Before the
Federal Communications Commission
Washington, D.C.

In the Matter of	)	
	)	
An Inquiry Into the Commission's	)	
Policies and Rules Regarding AM	)	MM Docket No. 93-177
Radio Service Directional Antenna	)	RM-7594
Performance Verification	)	

Comments of du Treil, Lundin & Rackley, Inc.

du Treil, Lundin & Rackley, Inc. (herein "dLR") hereby submits the following comments in response to the above referenced proceeding. dLR and its predecessor firms have provided engineering services to the broadcast industry since 1941.

I. INTRODUCTION

dLR applauds the Commission's initiative in opening this rulemaking into how the present policies and Rules, many of which have origins dating back over 60 years, might be modified to allow AM broadcasters to make use of modern technology, analysis methods, and the knowledge that has accrued through the licensing of the thousands of directional antenna systems in this country. We believe that, with present-day technology, it should be possible to improve the Commission's ability to ensure that the directional antennas of AM stations under their jurisdiction operate properly while, at the same time, greatly reducing their licensees' cost burden for maintaining them.

A general discussion of matters related to directional antenna performance verification precedes our specific recommendations for Rule changes. The general discussion provides some historical perspective, explains the uncertainties of the directional antenna performance verification process in the context of the overall AM interference avoidance process, and particularly focuses on the efficacy of moment method analysis for AM directional antennas.

A 1957 FCC report on "Suppression Performance of Directional Antenna Systems in the Standard Broadcast Band" is included as an appendix hereto, as it provides an analysis of what we believe to be the most complete set of empirical data ever compiled on the uncertainties surrounding directional antenna performance. We believe that an understanding of those uncertainties, along with the uncertainties of the propagation analysis and field strength measurement processes that are discussed herein, are of paramount importance in considering the equities of regulating the directional antenna performance verification process.

II. GENERAL DISCUSSION

A. THE BEGINNING OF AM DA TECHNOLOGY

We think that a brief review of the early history of AM DAs would probably be of good use in this discussion. The first DA built in the United States was tuned up in April of 1932 at the site in Bayview, Florida that was used by stations WFLA in Clearwater and WSUN in St. Petersburg on a shared-time basis. It was a two-tower array on 620 kHz, with quarter wavelength spacing between the towers that were oriented on a line toward co-channel station WTMJ in Milwaukee. The feed system was designed by Dr. Raymond Wilmotte to have the north tower lead the south tower in phase by 90 degrees so that a cardioid pattern with a null toward WTMJ would be produced. He had gone to great lengths in designing the RF networks and transmission lines to achieve the necessary phase shifts to produce the desired pattern, since there was no way to measure the phase relationship between the currents in the two towers in 1932.

The plan was for Dr. Wilmotte and the other consulting engineer working on the project, Commander T.A.M Craven (who later served as Chairman of the FCC), to adjust everything theoretically, by setting the network branches to the values they calculated for the required phase shifts, and then let the Federal Radio Commission's engineers decide whether the technology was valid by making nighttime skywave signal observations at WTMJ. In other words, they attempted to adjust the array by controlling its internal characteristics (as in internal proofing). The plan didn't work. They discovered something unexpected - mutual impedance - when they configured the system for DA operation. This caused the base impedances of the towers to be different in directional operation than they had been to be when driven one at a time, negating the efforts of the engineers to know the array parameters from the carefully measured characteristics of the power dividing and phasing system. They did not have any means for measuring the phase difference between the towers, much less any way to know what those currents needed to be to produce the required fields (such as moment method analysis), so they came up with Plan B to get the job done: they put someone a few miles out in the direction of WTMJ and changed the reactance of network branches experimentally until they found out what they had to do to get the field strength down at the observation point.

Every DA pattern that has been built since has been proofed with field strength measurements. We think that everyone will agree that it was the right thing for them to do in 1932. We think that we will all even agree that it was the right thing to do 50 years later in 1982, even though some of us were experimenting with a new technology that, along with modern developments in antenna monitoring equipment, showed promise for returning us to Plan A by then. Yes, moment method analysis was emerging at that time as a possible solution to the problem that had always made it impossible to rely on internal array parameter measurements to verify correct pattern adjustment: the inability to predict actual current distributions.

B. AM RADIO'S ENGINEERING CRISIS

Many directional antenna systems are out of adjustment today - based on our experience in the field, we believe that over fifty percent of them are operating with at least some of their parameters outside of their licensed tolerances - because scaled-back FCC enforcement and the economic conditions of the AM radio industry in the 1980s and 1990s led to lax maintenance practices. With the recent renaissance in AM radio broadcasting, radio station owners don't have much choice when it comes to finding competent consulting engineers to come out and work on their directional antennas. There are not enough qualified engineers to take care of the AM stations with directional antennas that now need their services. Along with the lax maintenance practiced by most AM station licensees over a period of at least a decade and a half came a decreased demand for the services of consulting engineers for directional antenna work… this discouraged new engineers from entering the field. The sad fact is that very few of the engineers who designed, adjusted, and proofed the thousands of directional antennas that we have today are still in practice and only a scant number of new experts have come along to replace them.

We don't believe that it is overstatement to say that the AM radio industry is in an engineering crisis. The scarcity of competent AM DA engineers is not acceptable. It is a stumbling block for stations that need work to be restored to legal operation. It will also impede facility improvements that would reduce interference and improve service within the AM band.

The obvious solution of training new engineers to do the required hands-on antenna system work is easier said than done, we are afraid. The work can be divided into two distinct phases: Phase One deals with adjusting the equipment to a specified set of parameters while Phase Two deals with simultaneously finding the operating parameters and analysis assumptions necessary to allow the hundreds of field strength measurements that are required for an FCC-type proof to be analyzed to show satisfactory performance. Both phases involve much more complicated and theoretically rigorous work than is normally required of the engineers who do the office work in this business, performing allocation studies and preparing the exhibits required for construction permit applications. Our experience is that an engineer with an interest in antennas and RF networks, fresh out of college, can be sufficiently trained to do Phase One work, which is fairly scientific in nature, in one to two years. Phase Two work, which typically has to deal with much more complicated matters related to the electromagnetic environment within the region where field strength measurements must be made, by its nature involves much more engineering judgment and, to a large degree, can be described as an art form. Our experience is that it takes a special person with exceptional abstract reasoning skills and a strong interest in mastering AM directional antennas to perform well in Phase Two, with several years of experience necessary before working independently.

We think that it is legitimate to question to what extent the requirements of the present FCC Rules might be contributing to this crisis. We believe that the answer is A LOT, and that the situation can be eased significantly if the Rules are changed to allow analysis techniques that can be demonstrated to be scientifically valid but that were not available when the Rules started out on their present course. Moment method analysis techniques can eliminate Phase Two work completely for many, if not most, stations. That would go a long way toward solving the AM radio's engineering crisis. Young engineers will be able to enter the market and reach the level of knowledge necessary to become experts in AM DA work much more expeditiously than is now the case. The Rules can safely be changed to reduce the amount of Phase Two work required for arrays having characteristics that prevent accurate moment method analysis, also.

C. AVOIDING UTOPIANISM

Utopia, from Greek words meaning "no place," is a hypothetical "perfect world." History teaches that great harm has been done by would-be Utopians who, though they might have been well meaning, squandered resources and lives seeking to reach that goal. We must avoid Utopianism in order to equitably evaluate the options for directional antenna performance verification, since "real world" conditions apply to radio wave propagation, the field strength measurement process, and actual directional antenna performance.

It is convenient to base engineering analysis on utopian or "perfect world" assumptions – such as saying that a 20% variation in radiated field from one station will cause a corresponding 20% variation in interference that is received at another station. Such analysis is attractive because it is simple. It is invalid, though, when the "real world" imposes a variability of more than 50% on the interference calculation process and all interfering signals exist only ten percent of the time. The "real world" conditions under which antennas radiate and signals propagate must be considered in the context of the overall interference avoidance process in order for the factors of directional antenna performance raised in this proceeding to be properly considered.

We realize that, for administrative convenience, the FCC must use go/no-go analysis procedures that might seem to look at first glance like they employ "perfect world" assumptions. The FCC was aware of the statistical nature of and potential for errors in the data upon which their procedures are based when they were first established. This goes for both the allocation process and the standard pattern calculation process. The uncertainties inherent in the directional antenna proof-of-performance process must now be considered in the context of this rulemaking. The following six areas of uncertainty come immediately to mind:

1. THE FIELD STRENGTH MEASUREMENT PROCESS IS FAR FROM PERFECT

To start with, just refer to a field strength meter's calibration certificate. Start reading where it explains the traceability of the calibration from the original standard source. You will see words that describe how the various intermediate standards are believed to be within certain percentages of the original standard and each other and then the percentages that your meter indication can vary from the final lab standard that was used to calibrate it on different scales. If you add up all the percentages, you will see that the meter is only stated to be capable of reading within about 8 1/2% of the true field value. That is 0.7 dB right there. We know that it is highly improbable that all of the errors will fall in the same direction and that field strength meters are generally more accurate than that, but this is just the "tip of the iceberg."

Take that field meter out and make some readings. You should know, first of all, that you are writing down numbers in mV/m of electric field that were read from a meter that is actually sensing magnetic field and doing the conversion by the scale on its meter face. This process assumes the characteristic impedance of free space. Look around - see the various configurations of conductors that can have currents induced in them all around you; realize that conductors that you can't see, because they are underground, can carry currents too and that localized field disturbances can result from changes in soil characteristics, terrain features, and land/water boundaries.

Take out a proof-of-performance report and look at the graph of the DA readings that were made on a null radial, where the critical protection requirements are typically found. In the majority of cases, you will see that the measured field strengths are scattered over a span of several dB - in the best of cases the scatter will be centered above and below the conductivity curve that was drawn through them. If the radial was run over complicated terrain, the span might be well over 10 dB. The word "proof" might appear in the title of the report, but when you look at the data and think about field strength meters and how they are used you have to realize that all that has been proven for some of the measured radials is that the measured field numbers given in the report are probably within several dB of being correct.

"Wait a minute," you might say, the probable error is small because randomness assures that they are +/- errors. This is the principle that underlies the kind of statistical analysis done on data such as is acquired by a surveyor laying out a straight line on a fixed azimuth from a reference point. He determines his azimuth reference within an acceptable +/- tolerance when sighting back to the reference point and the line will be quite accurately portrayed with several observations owing to the randomness of the errors. This is not what is going on with errors in measured field that result from influences external to the array. We believe that the situation is much closer to the one where errors are introduced in a poorly placed ship's compass which is "pulled" off azimuth by nearby magnetic field disturbances. Successive observations will have the familiar +/- error, and maybe even scatter due to the changing influence of the magnetic disturbance at different headings, but the errors will not be centered on the correct azimuth. Hence, statistical analysis of many observations might let you gain high confidence in defining some central value but it will not mean that the value is correct. You might solve for something like the mean erroneous value of field strength along a measurement radial in a proof-of-performance that way, but trying to relate it to the actual performance of the array is a process akin to trying to unscramble eggs. We do the best we can to get good data and get help from the standard pattern assumptions, but we are really not "proving" what many people like to think we are proving - the exact values of unattenuated field stated out to several decimal places - with external proofs.

2. PARTIAL PROOFS ARE SUBJECT TO CUMULATIVE ERROR

Most AM stations in operation today have had one or more partial proofs run since the original full proof measurements were made. The analysis technique required for partial proofs involves a comparison of present measured field strength data to the measurements that were included in the original proof report. This process is subject to error from two major sources - the inability to make readings at precisely the same locations after many years have passed and changing propagation characteristics. These errors are cumulative, because the required analysis technique makes them add to the error already present in the original proof-of-performance.

Anyone who has made field strength measurements for a partial proof-of-performance knows that you can often get at least 25% more or less field than you first measure by walking around in the area covered by the dot that was placed on the measurement map in the original proof-of-performance report to indicate the measurement location. When faced with the task of running a partial proof that must be accepted by the FCC, engineering judgment comes into play. Since the engineer running the partial proof cannot be expected to use exactly the same judgment as the one who ran the last full proof many years, or even decades, earlier, errors are bound to occur.

The matter of propagation conditions changing over time is a major and pervasive form of error resulting from the partial proof process. This happens in two ways: seasonal variation and long-term variation.

Seasonal changes can cause considerable variation in field strength during the year. The most pronounced changes occur with frozen-ground conditions in the winter, when the effective conductivity can increase greatly. It is not unusual to see the average field strength between two and ten miles (the distance span normally measured for partial proofs) along a radial increase by 50% or more in the winter in some parts of the country. If a full proof is run in the winter, then it is possible to go back in the summer, adjust the parameters to let the nulls out by 50%, and run a partial proof showing, through a comparison of field strength readings with the original proof, that the nulls are unchanged. The station files the partial proof with the FCC and then becomes licensed to operate with parameters that cause its null radiation to be 50% (3.5 dB) out of tolerance. It is our experience that there are many unintentional cases like this out there today, and we believe that there are probably others that were intentional.

Long-term variation, that might often be better called permanent change, is a major source of error for stations with full proofs dating back several decades. In their case, measured field strengths along radials are much lower for given amounts of actual radiated field owing to the fact that the land surrounding their transmitter sites was developed after their original proofs were run. As in the seasonal variation case, this makes it possible to "prove" that the radiation pattern is correct while, in reality, the parameters have been adjusted to produce unattenuated fields far in excess of the required standard pattern values. Our experience indicates that this problem is pervasive, though we believe that the examples we see were, generally, not created intentionally.

A partner in this firm has never forgotten the explaining that he had to do after tuning up a modified nighttime pattern for a class II station on a foreign clear channel that we had improved by obtaining a CP to increase the radiation in the nulls by about 50% in order to take advantage of a change in the allocation situation. When he got through adjusting the pattern so that it could be proofed for the CP standard pattern, one of the old null monitor points was about half of what it had been running for many years before the station's nighttime pattern was "improved." The station manager was about "fit to be tied" because the consulting engineer who was supposed to be making the coverage better actually made it much worse. The original proof had been run in the 1940s, and the station had been operating with something like three times (9.5 dB) higher radiation than allowed by the old standard pattern since a partial proof that had been run over 20 years earlier. We think that this error is more egregious than most, but our experience indicates that this type of error is fairly typical. We run into this type of situation all the time at older stations.

3. THE ALLOCATION SYSTEM IS FAR FROM PRECISE

We live in an imperfect world. This is seen in the process that we use for protecting our AM stations from nighttime interference. We currently use a propagation model that was developed in the 1980s by Mr. John Wang of the FCC to be an improvement over the methods that had been previously employed. In his paper entitled "Prudent Frequency Management Through Accurate Prediction of Skywave Field Strengths" that was published in the June, 1989 issue of the IEEE TRANSACTIONS ON BROADCASTING, Mr. Wang presented his case for why his method should be adopted. For the six North American propagation examples he offered, the RMS error for the prediction method that was adopted was 5.7 dB.

In general, exact calculation is also absent from the daytime allocation process. The calculations seem exact, but, when you take into consideration the fact that the figure M-3 ground conductivities of the FCC Rules are estimates that can vary widely from reality (in most cases overestimating field strength by a significant amount), they often are not. Field strength measurements are sometimes made to better define the ground conductivity in specific directions, but are generally made only to the extent required to make a desired radiation pattern "fit." In other words, enough measurements may be made on a station that must be protected from interference to pull its troublesome contour back by the necessary amount, with figure M-3 conductivity used for the remainder of the distance between the stations. A fair amount of error is to be expected in groundwave interference analysis, particularly considering that the type of seasonal variation mentioned in our discussion of partial proofs is also at play with allocations based on both M-3 and measured conductivities. Besides that, you generally face several dB of field strength uncertainty on the null radials of daytime directional antenna patterns due to scatter.

4. DA SUPPRESSION PERFORMANCE ISN'T PERFECT

The efficacy of proof measurements to determine the real interference potential of directional antennas can be much better understood by examining the information presented in the FCC Memorandum concerning "Suppression Performance of Directional Antenna Systems in the Standard Broadcast Band" by Harry Fine and Jack Damelin, dated September 6, 1957. [This Memorandum is being submitted as an appendix hereto.] In this report, which was prepared before the advent of standard patterns, analysis methods to correlate measured and theoretical far-field skywave protection for a number of actual stations were examined. All of the stations that were studied, were verified by the FCC to be operating properly under the Rules prior to observation. A quadrature component of 9.0% of pattern RSS was found to produce standard errors in the range of four to six dB. A quadrature factor of 2.5% of pattern RMS was ultimately adopted for largely political reasons, so the error would be even higher if the 1957 data were analyzed under the present standard pattern Rules.

5. AUGMENTATION GIVES FALSE VERTICAL RADIATION

In the case of nighttime interference protection, radiation above the horizontal plane is used to calculate the levels of signal arriving at other stations from a directional antenna. In general, nulls in an array's horizontal radiation pattern (only horizontal pattern measurements are made for a proof-of-performance) occur at different azimuths than the high-angle nulls that are required for interference protection. For example, if two towers are spaced 90 electrical degrees apart at an azimuth of 0 degrees true and it is necessary to provide a null in radiation toward a station along the tower line at a vertical angle of 30 degrees for nighttime protection, the phase difference between the fields of the two towers has to be 102 degrees. In the horizontal plane, this array will produce a pair of nulls at 30 degrees true and 330 degrees true with a minor lobe pointing toward the station that is actually receiving protection. If, during the adjustment process, it is necessary to set the array to different parameters in order to "crank around" local magnetic field disturbances along the null measurement radials and also augment the pattern in the null region before it can be licensed, much higher radiation toward the protected station can be produced without any recognition whatsoever. This is because the augmentation process specified in the Rules assumes that the increased field moves directly upward within the region of augmentation instead of following the corresponding pattern null as it rotates in azimuth. We believe that the potential for interference from this cause alone is of at least the same order of magnitude as all but the most egregious cases of nearby reradiating objects.

6. PATTERN BANDWIDTH DEFIES SIMPLE PREDICTION

In the case of adjacent-channel interference, carrier frequency pattern shapes are used to evaluate protection even though real-world directional antenna patterns assume considerably different shapes off-frequency where the sideband energy that causes the interference is radiated. This happens because the heights, spacings and, most importantly, drive impedances of array elements change with frequency. We have considerable experience with this phenomenon from the standpoints of both computer modeling and empirical measurement and we know that the effect can be quite pronounced, with sideband patterns sometimes producing 20 dB or more excessive radiation within 10 kHz of carrier frequency. It is not practical for the Commission to regulate this property of directional antennas, since a system's pattern bandwidth is a function of both the design and adjustment of its phasing and coupling system networks, so this remains a neglected area of directional antenna performance uncertainty.

D. THE LIMITS OF KNOWLEDGE

It is clear that we need to characterize the nature, limits, and validity of our knowledge about AM DA performance in the context of the overall interference avoidance process before we can talk intelligently about what should be required for proofing them. Two examples serve to illustrate this.

Here's a rather mundane and trivial example: If a learned scientist carefully measures a log and marks where it should be cut with a fine line accurate to +/- 0.001 inch and then it is chopped in two by a lumberjack who is capable of hitting it within +/- 1.0 inch of the line with his axe, can the learned scientist say after the lumberjack is finished that he knows the lengths of the two resulting pieces within +/- 0.001 inch? Of course not! How about 0.01 inch? Of course not! How about even 0.1 inch? Of course not! This begs the question of whether a specification should be written requiring that the logs to be cut by this lumberjack be marked to within 0.001 in the first place. Of course not!

Here's an example that is a little "closer to home" for us: If the interference avoidance process relies on DA suppression that has been demonstrated empirically to include at least six dB error, propagation analysis that has been demonstrated to include approximately six dB error, and an external proofing process that demonstrably includes several dB of error, do we know how well directional antenna patterns perform within the overall scheme of things to within a fraction of a dB? Of course not! Should we be quarreling over the importance of tenths of a dB, or even one to three dB, when deliberating how the proof Rules might be changed? Of course not! [This does not consider the comparison between moment method analysis and external proof uncertainties which we think, alone, justifies the adoption of moment method analysis techniques for the arrays that can use them.]

Recently, a client of this firm had to pay for a crew to go out and remeasure a major lobe (i.e. non-adjustable) radial for a partial proof because the initial readings were 1.1% (0.1 dB) high and there was not any way to "analyze them in." This exercise is sure to have cost them at least $1,000 in field strength measurement work, expenses, and delay in the analysis process. The radial was found to be barely "in" when it was remeasured.... apparently we were fortunate enough to catch some of the errors on that radial having a "down day." This is but one example of the absurdity of the present performance verification process.

The first step toward having the correct perspective when we look at AM DA performance as a part of the overall interference protection process, in our opinion, is to view the possible radiation errors in dB. The other steps of the process use dB and, for that matter, every other type of antenna that we are aware of uses dB for specifying performance.

E. AVOIDING LOGICAL FALLACY

We believe that we must agree to use valid logical thinking as we approach the question of what data should be required to demonstrate that an AM directional antenna is working properly. This means that we must avoid granting decisional significance to illogical arguments.

One common logical fallacy that those on both sides of the moment method analysis question need to avoid is CHRONOLOGICAL SNOBBERY : X is old/new, therefore X is good/bad or bad/good. Another is AD IGNORATIUM argument: I don't know if X is true or false, so X is therefore false. Another is AD BACULUM argument: an undesirable side effect is possible if X is true/false, therefore X is false/true. Another is AD POPULUM argument: most people presently believe X is true/false, therefore X is true/false. Another is BULVERISM: you believe X is true because of who you are, therefore X is false. And an important one is AD HOMINEM argument: P says X, we disagree with P about Y, therefore P is wrong about X. FALSE DICHOTOMY can be very misleading: X and Y are valid separately or together, you must choose between X and Y.

"We have to change the Rules because they were written many years ago," and "we should not change the Rules because they have stood the test of time" are both examples of CHRONOLOGICAL SNOBBERY. Neither alone is a reason to change or not change the Rules. "I haven't experienced success with moment method modeling, so it should not be considered" is an AD IGNORATUM argument. Maybe you should get some experience, or share someone else's. "The FCC should not stop requiring base current readings because they might stop making base current meters" is an example of an AD BACULUM argument. If there is no need for that type of meter, why make them? If there remains some need, it will be up to the law of supply and demand to set the price at which new ones can be made or old ones rebuilt. "Most people will still want to make field strength measurements, so the rules should not be changed" is an example of an AD POPULUM argument. Why should measurements that are not scientifically necessary be required because of the opinions of some individuals? "You just like moment method modeling because you are a computer jockey" is an example of BULVERISM. "You like moment method modeling but I think you are just too lazy to make field strength measurements like I've always made them, so you are wrong" is an AD HOMINEM argument. "We are at a crossroads where we have to choose whether DAs will be proven with computer modeling or field strength measurements" presents a FALSE DICHOTOMY. Allowing moment method analysis proofing of some stations will not prohibit others from being proofed with field strength measurements.

Using logical fallacy in ordinary language is not unusual. In fact, it is often used to convey one's feelings. It happens very easily when emotional controversy is involved as is obviously the case for the present discussion. When we get down to the process of evaluating the possibilities for changing the Rules on DA performance verification and the reasons that justify doing so, however, we should go about it in a scientifically valid and logical way. We must “filter out” logical fallacy when it comes to the decision making process. There must be sound reasons for what we decide to do and to not do.

F. WILLIAM THOMSON AND WILLIAM OF OCKHAM

We believe that we would do well to be illuminated by the thinking of two gentlemen who, in our opinion, long ago stated principles that are fundamental to science and the practice of engineering even today. They are William Thomson, a.k.a. Lord Kelvin, who lived in the nineteenth and into the early twentieth century and William of Ockham, a.k.a. William Ockham, William Occam, or simply Occam, who lived in the thirteenth century and into the fourteenth century.

William Thomson made a statement that is always near and dear to the hearts of empiricists. It is usually quoted this way: "When you can measure what you are speaking about and express it in numbers, you know something about it; when you cannot measure it, when you cannot express it in numbers, your knowledge is of the meager and unsatisfactory kind." These words, from a man who some call the father of modern science, could seem to suggest that field strength measurements are the only basis for defining a directional antenna pattern. He did not mean it that way.

It helps to understand what Lord Kelvin was talking about when the quote is completed by including the last sentence that is often omitted: "It may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science." Taken in its entirety, the statement simply says that it is necessary to be able to verify with measurements and quantify what you are talking about before you are "doing" science. It does not say that exhaustive and redundant measurements are necessary for scientific analysis. Indeed, Lord Kelvin himself developed the system of temperature measurement that bears his name to simplify thermodynamic analysis based on what was known about the behavior of gases in the nineteenth century, even though it would be decades before scientists could make temperature measurements anywhere close to the zero entropy point, or "absolute zero" temperature, upon which his scale was based. We think that he would heartily approve of the use of modern computational methods that, employing empirically derived or empirically verified scientific principles like Ampere's Rule, Faraday's Law, the Biot-Savart Law, and Maxwell's Equations, can greatly simplify the work of antenna analysis.

William of Ockham laid a very important "stone" for the “foundation” of modern science with the doctrine of simplicity expressed in his Law of Economy, otherwise known as "Ockham's Razor": "NON SUNT MULTIPLICANDA ENTIA PRAETER NECESSITATEM"; i.e., "entities are not to be multiplied beyond necessity", or, in more common english, "it is vain to do with more what can be done with less." The history of science is the history of a search for simplicity in explaining and analyzing the properties of the world and universe around us. An example of how Ockham's Razor has helped our understanding of science might be worded "it is a waste of effort to calculate the relative motion of the Sun and every body in our Solar System around the earth when calculations using the Sun as the reference point can be correct with much less computational complexity." [You can make yourself unpopular when you use Ockham's Razor to challenge emotionally-held beliefs, as Copernicus learned the hard way when he published roughly the same statement in the early sixteenth century.] The proper application of Ockham's Razor to the question of AM directional antenna performance verification would be to avoid accumulating data beyond what is necessary to demonstrate acceptable DA performance because additional information is meaningless for that purpose.

G. THE CURRENT DISTRIBUTION QUESTION

Moment method analysis uses modern computer technology to solve for the actual current distributions of array elements so that their radiating properties can be related to their drive currents and voltages using generally accepted, and empirically proven, laws of electromagnetics. This was not possible before moment method analysis, because antenna analysis was based on current distributions that were chosen for their mathematical simplicity instead of their real-world reliability. It had to be done that way back then, as it was not humanly possible to integrate the complicated functions that have to be used to completely replicate real-world conditions using the techniques of classical mathematics.

The most common current distribution assumption is sinusoidal current distribution. Most textbook analysis of linear antennas uses the sinusoidal current distribution assumption, as do the FCC's procedures for calculating radiation patterns. Even though it is easy to demonstrate that no antenna that is radiating can have purely sinusoidal current distribution, it has long been held to be "good enough" as far as calculating far-field radiation is concerned. We agree. The improvement in far-field radiation accuracy with moment method analysis may be significant in some instances, but we don't believe of a magnitude sufficient to "upset the apple cart" and redo all of the FCC Rules and international agreements that now rely on time honored sinusoidal current distribution assumptions at this time.

H. THE IMPACT OF MOMENT METHOD ANALYSIS

The impact of moment method analysis on antenna adjustment and proofing is nothing short of earth shaking. The big disadvantage of using current distribution "assumptions" is that you assume that every element of an array has the same form of current distribution. In other words, the relationships of the tower currents to their corresponding far-field pattern contributions are all assumed to be the same - leading to the conclusion that, with a perfect sampling system, you should see parameters on the antenna monitor equal to the field parameters for the desired DA pattern if verification by internal measurement is a valid concept. This is far from being the case. In reality, the current distributions vary significantly in the various elements of an array because each tower functions in both the radiating and receiving (from mutual coupling) modes simultaneously and its current distribution is actually the superposition of the two. Furthermore, the current distributions of the towers of an array change whenever the parameters are adjusted. This is why it has almost always been necessary to adjust the ratios and phases of the tower currents in an array to values differing from its DA field parameters in order to produce the correct radiation pattern, even with carefully constructed antenna monitor sampling systems.

The fact of non-uniform array current distribution has commonly been ignored, since it is not recognized in the FCC Rules. It was impossible to calculate the actual current distributions of DA array elements before the advent of moment method analysis, so it was impossible to relate the required far-field pattern parameters to quantities that could be measured on-site. This is why we proof antennas the way we do now, relying on an external field strength measurement process that itself has a large amount of uncertainty, especially in the important null region of a pattern where field strength measurement scatter can easily span a range of 10 dB along the length of a measurement radial. We believe that it is time to get rid of that uncertainty and the great expense that is required for the process that produces it.

I. MISUNDERSTANDINGS REGARDING MOMENT METHOD ANALYSIS

Although moment method analysis techniques are almost "old hat" by now to the larger antenna engineering community (you can find them discussed in just about any IEEE Antennas and Propagation Society periodical published in the last fifteen or twenty years), their use has been retarded in the AM broadcast field by the fact that the Rules in this country require that the techniques that were developed long ago employing the sinusoidal current distribution assumption still be used. We also believe that the old problem with relating the current and field parameters of the elements of AM DAs is responsible for much of the negative thinking that was evident in the comments filed in the earlier Notice of Inquiry of this proceeding. They have simply had so many experiences where very careful antenna monitor system design and installation still did not produce the correct pattern shape with the parameters adjusted to the "theoretical" values determined by the old methods that they are incredulous when told that a computer program can now let them do it.

Another major cause of misunderstanding and disagreement is that many consulting engineers purchased the moment method analysis software that was available "off the shelf" ten or more years ago and were never able to achieve satisfactory results when attempting to model AM DAs. The software worked, it just didn't have any built-in feature to solve for the drive voltages required to produce a desired set of antenna field parameters. It would give correct results for the array geometry and drive voltages that you put into it, it just didn't help find the voltages to use if you only knew the field parameters of the pattern. We believe that this is why several experienced and respected consulting engineers stated in their earlier Notice of Inquiry comments that their experience was that moment method analysis techniques could not be reliably used to model AM DAs.

Those who were successfully using moment method analysis techniques back in the earliest days had modified the software that was available at the time to relate the desired field parameters of an array to the voltage drives required by the moment method analysis programs. The technique involved inverting large matrices filled with complex numbers - something that is not particularly easy to intuitively understand - and apparently few people ever "tried it at home." Fortunately, programs that do the complete job of modeling AM DAs are available today from several sources - the user only has to learn how to set up the array geometry using appropriate assumptions to be in the "moment method analysis business."

We suggest that, before attempting to address the issues that will have to be dealt with when the new Rules are written, we pause to let the larger community of engineers gain experience with moment method analysis techniques. A Further Notice of Proposed Rulemaking would be a good vehicle for accomplishing this without interrupting the process that is currently underway to simplify the requirements for proofs that employ field strength measurements.

J. INTERNAL VS EXTERNAL PROOFING

We refer to using moment method analysis techniques to proof an antenna pattern as an "internal" process, since the system is adjusted to produce the correct internal array parameters. Likewise, we call the conventional field strength measurement proof process an "external" one, since it relies on field strength measurements made external to the array. Accepting the amount of uncertainty inherent in the external proofing process was the thing to do before moment method analysis came along, since we were not able to correlate any internal measurable quantity to the far-field pattern parameters of an array. External measurements were superior to internal measurements for determining that an antenna pattern was correct. An uncertain process focused on reality was superior to an uncertain process (even if the degree of uncertainty could be decreased with a high quality antenna monitoring system) focused on the unknown. Once the proof was completed with field strength measurements, the internal parameters were useful for maintenance purposes. Antenna monitor systems are presently designed for that use and the parameters observed at the time of an external proof are placed by the FCC on station licenses for maintenance purposes.

Now that we can make the correlation between antenna element currents and actual field parameters, we have the opportunity to clean up the process by deciding how internal array parameters can be monitored with sufficient precision to overcome the disadvantages that are imposed by real-world conditions on external field strength measurements. It will likely require that more money be spent on antenna monitoring equipment, but the savings in time and expense for proofing patterns will far outweigh the increase for many licensees.

K. MOMENT METHOD ANALYSIS MAKES INTERNAL PROOFING POSSIBLE

Now that it is possible to model actual array element current distributions, we believe that it should be possible to determine that a DA system is operating properly by observing that the element currents or voltages are correct. A proof-of-performance under this scenario would focus on a very thorough validation of the sampling system. Sampling systems would be constructed to higher standards than they are today, and might include self-calibrating or self-testing features.

We have adjusted many DAs using moment method analysis in the last 15 years or so. We generally find it desirable to make small adjustments from the initial moment method analysis parameters once a "sampling" of filed strength measurements have been made to "squeeze" some nulls down by a dB or two to be within the standard pattern with reasonable monitor point tolerance or, sometimes, work certain nulls out toward the standard pattern envelope for coverage improvement. There have been times when we found it reasonable to just leave the parameters at the moment method analysis values for the proof. In no case, even with complicated terrain and/or unequal height towers where the applicability of computer modeling might be questioned, have we ever seen any radial as much as five dB outside of the standard pattern where unobstructed radial field strength measurements were possible. The largest such deviation we remember was about three dB. Most have been in the zero to two dB range. The scatter of the groundwave field data that you typically find when you run a null radial in a proof is about the same as the highest dB error we have experienced setting up arrays with moment method analysis techniques, and the errors that were found in the FCC's own suppression performance and skywave propagation studies were significantly higher.

We believe that it should be possible in many if not most cases to proof DAs with moment method analysis techniques and get better results, in terms of the actual objective of interference avoidance, than we realize today with the thousands of arrays that have been proofed with the procedures required by the present Rules. Having said that, we also believe that there are some systems that, because of their electromagnetic environments or inherent characteristics, are not candidates for moment method analysis. We should review the present requirements for field strength measurement proofs to see how they can be streamlined for those arrays and others that might otherwise qualify for moment method analysis but have licensees that choose to do otherwise. We can have Rules that allow great flexibility for conducting proofs by recognizing the advantages of the latest technology where it can reasonably be applied.

The uncertainty of the external proof process can be reduced or at least traded for a level of uncertainty that is no greater with an internal proof process at a great overall cost savings in most cases. It is good engineering practice to find the most cost-effective solutions to problems. That should be a major consideration of this rulemaking.

III. RECOMMENDED CHANGES

With consideration to the foregoing general discussion, we have developed responses to many of the points raised by the Commissions "Notice of Proposed Rulemaking" in this matter. Our responses are provided in the order of that document:

<u>Computer Modeling versus Proofs of Performance</u>

We do not agree with the name of this topic, since we do not believe that it is an either/or question. We believe that computer modeling can become a component of Proofs of Performance with great benefit to the FCC and the broadcast industry. We recognize that not all directional arrays have characteristics that lend themselves to computer modeling and that work remains to be done before the industry will be ready to adopt standards for computer modeling in the cases where it can be used. We urge the Commission to issue a Further Notice of Proposed Rulemaking to study matters related to computer modeling of AM arrays while continuing with the process that is already in motion to simplify the requirements for conventional field strength measurement-based performance verification.

Directional Antenna Proofs of Performance

We believe that the Rules should be simplified for all AM stations with the understanding that certain stations may opt for computer modeling-based proofs at a later date depending on the outcome of the requested Further Notice. The simplified Rules will apply to all stations initially, and the process of making them should be expedited.

Number of Radials

We believe that there should be no minimum number of radials. Only the radials required to demonstrate that the parameters of the array have been adjusted to produce the required field vector summation should be required to be measured; i.e., radials should be required only at the pattern minima and any maxima that are less than the RMS of the standard pattern. There should be no requirement for maximum azimuthal separation of radials.

Additional radials should not be prohibited. The small number of stations that need to run transmitter power higher than the nominal power in order to make minimum RMS should have to base their RMS analysis on at least one radial for each directional pattern maximum and minimum.

Number of Points per Radial, Length of Radials

We believe that there should be no requirement beyond a DA/ND ratio analysis of 10 points per radial, assuming a ND inverse field selected to be within 20% (1.6 dB) of the theoretical ND field for the tower used for the ND measurements. No measurement graphs or close-in measurements should be required for stations that can demonstrate compliance with their standard pattern requirements by these means.

Most arrays now are adjusted to parameters that were set at the time of a partial proof through an new-old DA/DA ratio process that we believe has considerably higher uncertainty that would result with this plan. We believe that the evidence from the thousands of ND proofs that are on file with the FCC clearly demonstrates that there are not any significant number of stations with ND radiation patterns having maxima as high as 25 % (1.9 dB) above the theoretical ND field, even when reradiation from unused towers on the property that were not properly detuned is obviously at play. For worse case purposes, a DA pattern proofed on the basis of our proposed DA/ND method with an assumed ND field 20% on the optimistic side and an actual radiation 25% higher than theoretical would result in an error for the measured null or minor lobe of 3.5 dB – approximately one half the RSS dB uncertainty that is inherent in the other phases of the overall interference avoidance process.

ND stations that do not have to conduct proofs to become licensed can have eccentric radiation patterns and/or low RMS on the same order of magnitude as would stations with DA systems proofed according to our plan, for many of the same reasons. The simplified measurement process we propose would serve to reduce the inequity in the processes through which DA and ND stations are licensed.

We believe that those who wish to do so, or who need to demonstrate low RMS in order to request higher power, should have graphical analysis as an option. Five additional points, preferably taken within the first 3 kilometers, should be required for ND graphical analysis, making a total of 15 points per radial for ND operation. Only 10 points should be required for DA analysis, as in the case of arrays that do not require ND graphical analysis.

We do not believe that the Commission should set rigid standards for radial length. There is a great variation in electromagnetic environment from station to station. For one station, it might be necessary to take the 10 measurements required for DA analysis within the first six kilometers to avoid a mountain range; for another, it might be necessary to take them between 10 and 25 kilometers to avoid nearby magnetic field scatterers and get into the far field of the array.

We support the concept of a standardized electronic format for all of the data required for a proof of performance to streamline the Commission's processes.

Partial Proof of Performance

We believe that partial proofs should be abolished from the Rules because of their inherent inaccuracy and susceptibility to cumulative error. The full proof of performance procedures that we have proposed will make it possible for most if not all stations to conduct proofs with less effort and expense than is now required for partial proofs. If computer modeling-based proofs are ultimately adopted for some stations, partial proofs will be irrelevant for them.

When [Proofs] Required

The circumstances requiring full proofs should be the same as they presently are for both full and partial proofs, with the exception that it should be possible to make changes of any type (not just sampling system components – things such as STL and FM antennas as well) above the base of a tower without any requirement for a proof if the before and after parameter and monitor point observations indicate that there has been no adverse effect.

Monitoring Points

We agree with the Commission's proposal to simplify the process of selecting replacement monitor points. Further, we urge the Commission to allow monitor point maximum values to be raised on the basis of 10 measurements (including the monitor point) without requiring an entire proof. This will eliminate the inequity in the present rules that allows a new point to be selected and assigned a maximum value based on single-radial measurements but does not allow an existing monitor point's maximum to be raised by the same process.

Base Current Ammeters

We agree with the Commission's proposal to eliminate the base current metering requirement for directional antennas. In our experience, a properly constructed antenna monitor sampling system, constructed in accordance with modern standards, provides sufficient instrumentation for maintaining AM directional arrays.

Antenna Monitors

We agree with the Commission's proposal regarding specification of the requirements for antenna monitors.

Impedance Measurements Across a Range of Frequencies

We agree with the Commission's proposal to eliminate the requirement for measuring common point and base impedance across a band of frequencies.

Common Point Impedance Measurements

We agree with the Commission's proposal to eliminate the requirement that the common point reactance be adjusted to zero ohms. The requirement serves no purpose in the power determination process; ND stations determine power with base impedances that contain high values of reactance. It is our experience that it is generally necessary to set a station's common point impedance to have several ohms of negative reactance to provide a unity power factor load at the transmitter's output terminals owing to the series inductance that is present ahead of the measurement point. Licensees should have the latitude to set their reactance to whatever value suits their transmitter without having to ask for a Rule waiver every time as is now the case.

Critical Arrays

We believe that the critical array designation should be removed from the Rules. They no longer serve their original intended purpose – as punitive actions against stations wishing to share frequencies with the older stations that petitioned to have their antennas designated as "critical" – because changes in the operator and remote control Rules that were enacted a decade or more ago have eliminated the financial disadvantages of operating them. We believe that it is a great injustice, an egregious example of unequal enforcement of the law, to have the small number of stations that are now designated as critical while a much greater number of the presently licensed stations would have to be similarly designated if their patterns were subjected to the same scrutiny and held to the same standards.

The present critical arrays were so designated without proper consideration of the nature of array parameter variation in the context of signal propagation uncertainty. It seems ludicrous to us to require a station to maintain loop currents and phases within very tight tolerances for each array element because a set of parameters with small changes in ratio and phase of certain towers could be found to cause radiation outside the standard pattern, without any consideration of the probability of such parameter variations ever occurring or evidence that interference would result from the excursion outside of the standard pattern envelope.

We appreciate the Commission's attempt to propose a rule change that would be more fair with regard to the critical array designation, but find that it falls short of being equitable on one very important point: the amount of variation found to require critical array designation for the worst-case element of the array would be applied to all of its elements uniformly. In other words, if an array with elements having ratios ranging from 0.2 to 2.0 were found to meet the criterion for critical designation with a 1% variation in the ratio of the tower that has an operating ratio of 2.0, that 1% tolerance would be applied to the tower with a ratio of 0.2 as well – in effect limiting the variation of field from that tower to 1/10 of the vector field variation that led to the critical designation in the first place. We believe that the uncertainties of pattern behavior with parameter variation are no greater than the uncertainties in the allocation and propagation processes, making it unnecessary for the Commission to go to the trouble of assigning a different ratio and phase tolerance for each element of an array in order to address this inequity.

Other Matters

We believe that the electronic filing process can be streamlined if the requirement for filing field strength measurement maps is replaced with a requirement for the maps used in a proof of performance to be maintained in a station's records. The same goes for the map showing the monitor point locations. We see no reason to file polar plots of patterns unless the proof of performance analyzes the measured pattern RMS to request higher operating power… a tabular summary of measured pattern data would serve the purpose of demonstrating compliance while further streamlining the graphic content of a proof of performance report.

IV. CONCLUSION

The Rule changes proposed herein should improve the Commission's ability to know that our nation's AM directional antenna systems are functioning properly while greatly reducing the cost burden on their licensees. We estimate that proof-of-performance costs will decrease as much as five-fold, or more, if such Rules are enacted.

We ask the Commission to give our proposals serious consideration in this rulemaking process.

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November 9, 1999

APPENDIX

FEDERAL COMMUNICATIONS COMMISSION
Washington 25, D. C.

September 6, 1957

INTER-OFFICE MEMORANDUM

FOR: Information

TO: Chief Engineer

FROM: Chief, Applied Propagation Branch

SUBJECT: Suppression Performance of Directional Antenna Systems in the Standard Broadcast Band.

The attached report has been prepared to supply information which has long been needed for allocation in the standard broadcast band. It is believed that some of the results will be of appreciable use to the Broadcast Bureau.

Harry Fine

Harry Fine, Chief
Applied Propagation Branch

Jack Damelin

Jack Damelin

This report is "Supression Performance of Directional Antenna Systems in the Standard Broadcast Band" and is T.R. R. Report 1.2.7.
(The original cover is non-copying blue with black print)

SUMMARY

(1)

The suppression performance of directional antenna systems in the standard broadcast band is studied both near-in to the arrays and at the greater distances in the range of the skywave fields. In both cases, it is found that the measured fields are greater than the theoretically calculated fields, assuming perfectly conducting smooth earth, the departures increasing with the theoretical suppression and being much more substantial for the skywave fields. Methods are developed to estimate the average and maximum effective radiated fields expected in these suppression directions. In addition, based on the form of these estimates, the probable nature of the physical mechanisms, which cause these departures from theory, is discussed. For the close-in fields, the departures are probably caused by radiation from large objects and reflection from gross irregularities of the terrain in all azimuthal directions, whereas for the skywave fields - these departures are most likely caused by incoherence in the fields from the individual elements of the array, introduced by scattering from terrain and ionospheric irregularities.

INTRODUCTION

This report is a study of the suppression performance of directional antenna systems in the standard broadcast band (540 - 1600 kc) both near-in to the arrays and at the greater distances in the range of skywave fields. For years, the operating performance of directional arrays has been treated as a matter of judgement by experienced engineers and few attempts have been made to systematize the results of the available measurements although the need for such a study has long been recognized. An attempt will be made here to correlate the measured with the theoretical performance in order to give practical systematic estimates which are believed to be better in most cases than sheer judgement. Also, it is hoped from this study to arrive at a better understanding of the fundamental physical processes involved in radiation from directional antennas in the standard broadcast band.

The study will be divided into two parts. The first will treat with the close-in groundwave fields, as measured in proofs of performance submitted to the Commission. The second part will study the skywave suppression measurements on directional arrays, made in April 1949 by NARBA Committee IA.

NEAR-IN PERFORMANCE

For this type of performance, there are much data which have been submitted to the FCC in various proofs-of-performance for standard broadcast facilities. These horizontal radiation patterns for the directional arrays have been measured near the arrays but far out enough so that the array appears to be approximately a point source.

Selected for the study were the measured patterns of 13 arrays in 55 azimuthal directions with the greatest emphasis on those directions involving the greatest suppressions. The directional arrays were also chosen to have a wide practical range of frequency, ratio of Erss to Erms, and ratio of Emax to Erms; where Emax is the maximum horizontal field of the array, Erms is the horizontal R.M.S. (root-mean-square) field corresponding to the average power in the horizontal plane, and Erss is the horizontal R.S.S. (root-sum-square) field of the individual antenna elements. These data are plotted in Figure 1 in the form of measured versus theoretical horizontal inverse distance fields per kilowatt at one mile. With this type of plot, the greater the suppression - the smaller would be the inverse distance field radiated in the direction of suppression per kilowatt of average array power. As expected, the measured fields do not generally give the suppressions predicted by the theoretical fields for perfectly conducting smooth terrain; the departures from the theoretical fields increasing with the theoretical suppression. It is apparent that the theoretical fields, as such, may not be used for estimating the true performance of directional arrays, especially when large suppressions are involved. RSS

It seems reasonable to expect, assuming the arrays are properly adjusted that the main sources contributing to the discrepancies between the measured and theoretical fields are:

1. Re-radiation from large objects and reflection from gross irregularities of the terrain in all azimuthal directions about the array,

2. Reflection from smaller off-path objects and less irregular terrain in the same general direction,

3. Changes in the fields of the individual elements of the directional array because of irregular terrain.

Presumably, the effects of finite ground conductivity are made negligible by using the inverse distance fields at one mile, obtained by matching the measured field intensity versus distance curves against those calculated for finite conductivity. Which of the above sources are mostly responsible for the appreciable departures from theoretical fields may be determined by the correlation studies which were made of the measured fields with the maximum theoretical fields for various horizontal bracket angles, with Erms fields, with Emax, and with Erss.

Figures 2, 3, and 4 compare the measured fields with those estimated by adding the theoretical field for the pertinent azimuthal direction in quadrature with the indicated percentages of the theoretical Erms, Emax and Erss fields. A similar curve could have been drawn, using the maximum theoretical horizontal field within some bracket angle but the results along these lines showed less correlation and greater departures than did Figures 2, 3, or 4. The percentages used in Figures 2, 3, and 4 are the ones giving the best fit to the data for these various approaches considering the logarithm of the field intensity as the fundamental unit. These optimum percentages were found mainly by trial and error procedures.

By visual observation or even by comparing the standard errors, it is almost impossible to determine whether the Erms estimates of Figure 2 or the Emax estimates of Figure 3 shows the better correlation. No combination of Erms, Emax, and Erss gives any significantly better fit to the data.

The dependence on the Emax and Erss fields, shown in Figures 3 and 4 respectively are not significant fundamental correlations, as may be seen by examining Figures 5, 6, 7 and 8. Figures 5 and 6 show the deviations of the measured fields from the Erms estimates of Figure 2 when plotted against the ratios of Emax/Erms and Erss/Erms, respectively. If there were any fundamental trends with Emax or Erss, they would show up on this type of plot. To complete the proof that the only significant fundamental correlation is with Erms, there are plotted in Figure 7 the deviations from the Emax estimates of Figure 3 versus Emax/Erms, and in Figure 8 the deviations from the Erss estimates of Figure 4 versus Erss/Erms. These latter two plots show that there are trends still left when Emax or Erss are used as the basis for estimates. Apparently, the practical ranges in variation of Emax/Erms and Erss/Erms are so small compared to the variation of the data that artificial trends in Emax and Erss are produced.

Figure 9 shows that there are no frequency trends to be considered, at least in the standard broadcast band, when the Erms estimates are used. A similar plot, not shown, of the deviations from the Erms estimates versus the number of elements in the array, would indicate that the number of elements in the array does not affect the quality of the estimate.

Figure 9A is a plot of the deviations of the measured fields from the Erms estimates of Figure 2 versus the theoretical fields. This plot shows that the scatter is spread over most of the range of theoretical fields. It is to be expected from practical considerations that the scatter would decrease for the higher fields where the extraneous scatter fields represent a smaller percentage of the on-path radiated field.

Many of the data points in Figures 2, 3, and 4 represent different azimuth angles for the same station. In the analysis, the data was weighted so that all points within a 90° spread had the same total weight as a single independent point. Using this system of weighting, the results were the same as would have been obtained without weighting.

It has thus been found that the best estimate for the near-in suppression fields is given by the root sum square of the theoretical smooth earth field in the pertinent direction and 3.5% of Erms. The standard error for this type of estimate was 2.8 db. However, this standard error applies to freshly adjusted arrays, since the proofs-of-performance measurements, used in this study, fall into this category. It is expected that as time progresses, the currents and phases in the various elements of the array may vary, some appreciably.1/

1/ F.C.C. Report No. T.R.R. 1.2.6 "Physical Limitations to Directional Antenna Systems in the Standard Broadcast Band" by Harry Fine.

However, these variations will not usually affect Erms much, although they may change the theoretical field greatly, especially in directions of high suppression. Consequently, these operating variations should not affect too greatly the measured fields, since the contribution of the theoretical fields in these critical null directions is usually much less than that from Erms. As an educated guess, the standard error for estimating the suppression fields by the Erms method of Figure 2 should be in the order of 3.5 db for all arrays, including those not freshly adjusted.

In practice, an applicant for standard broadcast facilities submits to the Commission a theoretical horizontal radiation pattern for the directional array and superimposed upon this pattern are drawn M.E.O.V. (maximum expected operating values) estimates for those critical azimuthal directions in which objectionable interference might occur. These proposed M.E.O.V. fields depend mostly upon how much tolerance can be allowed and also upon the experienced judgement of the designing engineer. Figures 10 and 11 show that the minimum M.E.O.V. tolerances can be set systematically by adding the theoretical field in quadrature with approximately 15% of the horizontal R.M.S. field.

Having determined that the deviations of the measured from theoretical fields show by far the greatest correlation with the R.M.S. fields, the physical mechanism which causes the fill-in of the nulls of directional arrays becomes somewhat clarified. Since the R.M.S. field is a direct measure of the average power radiated in the horizontal plane, the fill-in of the nulls must be caused mainly by fields which are likely to come from any azimuthal direction. Only re-radiation from large objects and reflections from gross irregularities in the terrain around the array could supply these fields from all directions. The 2.8 db standard error would be explained by the irregularities in height, angle of reflection, and horizontal spacing of these large re-radiating objects and of the irregular terrain.

Summing up the results of this section, it has been found that the near-in fields which are measured for freshly adjusted directional antenna arrays can be estimated with a standard error in the order of 2.8 db by adding the theoretical fields in the pertinent azimuthal direction in quadrature with 3.5% of the horizontal R.M.S. fields. In addition, the minimum M.E.O.V. tolerances can be systematically set by adding the theoretical fields for the pertinent azimuthal directions in quadrature with approximately 15% of the horizontal R.M.S. fields. Finally, from the above correlation study, it appears that the fill-ins of the nulls are caused mainly by re-radiation from large objects and reflection from gross irregularities of the terrain in all azimuthal directions.

The performance of directional antennas in suppressing skywave signals, received at distances greater than several hundred miles will be considered in this section. Estimates from the theoretical calculations based on perfectly conducting smooth earth will be developed for the effective skywave radiated fields.

Back in 1949, the government-industry Subcommittee IA of the NARBA (North American Regional Broadcasting Agreement) Preparatory Committee began this type of investigation with measurements on 28 directional arrays at 22 different recording sites within the single hop E layer reflection range. Beyond submitting a preliminary summary of the theoretical and measured suppression ratios, this study was never completed, unfortunately. These measurements represent the best data available. For the present study, the data over 55 paths from 14 stations to 16 different recording sites were selected from the NARBA data. This data was selected both for reliability and to give as wide a spread as possible with frequency, distance, number of elements, Erss/Erms, and Emax/Erss.

The measurements were made throughout the night after regularly scheduled operations in April, 1949 by running the broadcast stations continuously for several nights on the following cycle:

a) 9 minutes of directional operation
b) 1 minute of silence
c) 9 minutes of non-directional operation
d) 1 minute of silence

Before the measurements were started, the arrays were adjusted to rated performance by the station engineers who had originally adjusted the arrays.

Non-directional operation was obtained by feeding a central element plus grounding and de-tuning the other towers of the array. Actually, one of the important factors considered by the NARBA Subcommittee IA in selecting stations was their ability to operate with non-directional characteristics, so that most of the stations selected for these tests operated regularly as non-directional during the daytime, and the others could be easily converted for the tests. Adequate checks were made to ensure proper non-directional operation. By measuring the ratios of non-directional to directional fields, the uncertainties of path attenuation were eliminated or at least minimized.

The selected data is plotted in Figure 12 as measured versus theoretical suppression ratios at the pertinent elevation angle. If the measured and theoretical ratios agreed, the 45° line would be the locus of the data points. It is apparent that the measured ratios show much less suppression than the theoretical ratios, the divergence increasing as the theoretical suppression ratio increases.

There are a number of physical factors which could affect the suppression ratios. Chief among these are:

1. Scattering from irregular terrain in the general direction of the pertinent azimuth angle will modify and cause the vertical radiation patterns for each element of the array to differ from theory as well as from the patterns of other elements of the array, even though the physical tower heights are the same. Further departures may occur because the element used for non-directional operation may have its vertical pattern modified.

2. Reflection from gross irregularities in the terrain and reradiation from large objects in all azimuthal directions from the array may modify the suppression.

3. Ionospheric irregularities will increase the incoherence caused by the ground scatter. Thus, if the vertical patterns from every element have different lobes, the ionospheric reflection areas for the main contributions from each element to the resultant received fields may well be different.

4. The finite conductivity of the ground modifies the vertical radiation pattern and causes a tuck-in at small angles of departure from the ground, resulting in vertical plane overhangs. This overhang increases, with distance from the transmitting antenna.2/ Consequently, calculations based on perfectly conducting ground would be in error. In the present instance, this factor is relatively unimportant, except insofar as it affects ground reflections for the case of arrays with equal height elements such as most of these were, since it affects the vertical antenna pattern factor about the same for all the elements of an array and such effects would tend to cancel out in taking the ratio of non-directional to directional operation.

2/ "Skywave Field Intensity I" by J. A. Pierce, Technical Report No. 158, Cruft Laboratory, Harvard University.

In order to determine which sources contribute mostly to the appreciable departures from the theoretical suppressions, correlation studies were made of the measured suppression ratios with those estimated from the maximum theoretical fields for various combinations of vertical and horizontal bracket angles, from the theoretical root-sum-square fields, from the theoretical maximum fields in any azimuthal direction, and from the theoretical root-mean-square fields. It was found that the use of bracket angles showed the poorest correlation. Whether the root-sum-square maximum and root-mean-square fields for the pertinent vertical angles were used or whether the corresponding horizontal plane values were employed made negligible difference, so that the results in terms of the horizontal fields will be shown since the solutions are more practical.

Figures 13, 14, and 15 compare the measured suppression ratios with those estimated by adding the indicated percentages of the theoretical Erss, Emax, or Erms fields in quadrature with the theoretical directional field at the pertinent elevation angle. The percentages used in these figures are the ones giving the best fit to the data, considering the logarithm of field intensity as the fundamental unit. These optimum percentages were also found chiefly by trial and error.

For this case of received skywave signals, it is found that the best estimates of the experimental data are in Figure 13, where 9% of Erss was added in quadrature to the theoretical directional fields at the pertinent vertical angles and in the pertinent azimuthal direction. The standard error of estimate was 4.2 db. No combination of the Erss, Emax, and Erms fields gave any more significant estimates.

As for the previous case of the near-in fields, the spread of the data with respect to Emax/Erss and Erss/Erms was not large enough to show which of the above fields had true correlation with the measured data. These artificial correlations are again best observed by studying the deviations of the measured from estimated suppressions. Figures 16 and 17 show the deviations from the Erss estimates of Figure 13 versus Emax/Erss and Erss/Erms, respectively. Figure 16 shows no trend with Emax, whereas Figure 17 indicates that there may be a slight trend with Erms, but any such trend is not significant considering the scatter of the data. Figure 18 is a plot of the deviations from the Emax estimates of Figure 14 versus Emax/Erss, and Figure 19 shows the deviations of the Erms estimates versus Erss/Erms. Both indicate that definite trends with Erss remain. Thus, it is apparent that of the three estimates - only that from Erss gives a significant fundamental trend.

Figure 20 is a plot of the deviations from the Erss estimates of Figure 13 versus frequency. There appears to be a slight trend with frequency, but it is not significant statistically within the standard broadcast frequency range. Figure 20A shows the deviations from the Erss estimates as plotted against the theoretical suppressions. Surprisingly enough, the deviations are scattered fairly uniformly over most of the range of theoretical suppressions and do not increase markedly as the suppression ratios increase beyond about 10. Figure 21 shows that the quality of the Erss estimates does not vary with distance in the one hop E layer reflection range. Likewise, a similar plot of the deviations from the Erss estimates versus the number of elements in the directional array would indicate that neither the estimate nor the scatter of data depends upon the number of elements.

It should be pointed out that many of the data points represent measurements on the same arrays at slightly different azimuthal angles, giving undue weight to such arrays unless some method of weighting is employed. In the present analysis, the points were weighted so that all points for the same array representing azimuthal directions less than 90° apart have a combined weight of a single independent point. It was on this basis that the standard error for the Erss estimate of Figure 13 was evaluated as 4.2 db, although if all points were given equal weight, the standard error would have been 5.2 db.

The standard error of 4.2 db represents the combined error or deviation in both the directional and non-directional fields. For the present purposes, only the directional field and its standard error are of interest. It can easily be shown that the greatest contribution to the standard error of Figure 13 comes from the variability of the directional fields. Thus, the measured suppression ratio might be represented as

$$(1) \quad R = \frac{End + \Delta nd}{Ed + \Delta d} = \frac{End}{Ed} \cdot \frac{1 + \Delta nd/End}{1 + \Delta d/Ed}$$

where E is the theoretical field intensity, Δ is the deviation from theoretical, and the subscripts nd and d refer to non-directional and directional operation, respectively. For equal radiated power, Erss will be roughly of the same order of magnitude for directional or non-directional operation, as will be the estimates for Δnd and Δd which are proportional to Erss. Therefore, Δnd/End will be much smaller than Δd/Ed in directions of suppression. Thus, it is apparent that most of the deviation from the theoretical suppression ratio is caused by the deviation in the directional field, since Δd/Ed is the largest factor in the above equation.

The standard error of the Erss estimate for the effective radiated directional skywave field is then about 4 db. However, it should be remembered that these arrays were all adjusted immediately prior to the measurements so that some allowance should be made for operational variation of the array. This variation in the array tuning and adjustment may greatly affect the theoretical directional radiated field in the pertinent direction but should not affect very much the Erss, so long as the radiated power is maintained within the limits prescribed by the Commission. Consequently, in those directions for which a large amount of suppression has been designed -i.e.

$$E_d \leq \frac{1}{10} \text{ Erss}$$

the received skywave field should not be too sensitive to operational variations of the currents and phases in the elements of the array. In addition, this standard error for the operational variation should be added in quadrature - i.e. root sum squared - with the 4 db standard error in the estimate. Thus, in those directions for which a suppression has been designed, the overall standard error of estimate should be in the order of 6 db for the effective radiated field estimated by adding the theoretical field in the pertinent direction in quadrature with 9 percent of Erss. It should be pointed out that in estimating the accuracy of a received skywave field, it would be necessary to add in quadrature with the above 6 db a standard error for the propagation curves used, since this type of error was made negligible by measuring the ratio of non-directional to directional fields.

Figure 22 compares the measured ratios with those calculated by adding 25% of Erss in quadrature with the theoretical directional field at the pertinent angle. It is seen that nearly all the measured suppression ratios are greater than these calculated values, so that this type of estimate may be used as rough gauge of the minimum suppression to be expected from a given directional array.

It is to be noted that since the ratio of Erss/Erms is a rough measure of the stability of the array, 3/ the more stable the array the smaller will be its Erss for a given Erms and the better will be its suppression performance.

3/ F.C.C. Report - T.R.R. No. 1.2.4 "Directional Antennas in the Standard Broadcast Band" by Harry Fine.

It has been shown 1/ that the resultant deviation, caused by incoherence or random deviations in the fields from the individual elements of an array, is proportional to the R.S.S. (root sum squared) field of the array. Therefore, the physical mechanism which causes these departures of measured from theoretical suppressions should be chiefly a combination of scattering from irregular terrain and ionospheric irregularities. Thus, the scattering from irregular terrain causes each element of the array to have a different vertical radiation pattern, so that the maximum contribution at the receiving end is made by fields radiated at different elevation angles from the individual antenna elements and reflected from different blobs in the ionosphere.

Summarizing the results of this study on received skywave fields, it has been found that the measured effective radiated fields in the null directions are much greater than the corresponding theoretical fields in the pertinent directions, this deviation increasing as the theoretical null increases. These deviations are apparently caused by incoherence, introduced in the fields from the individual elements of the array by scattering from irregular terrain and ionospheric irregularities. It has been found that fair estimates of the effective radiated fields in these directions of suppression are given by adding the theoretical field in the pertinent direction in quadrature with 9% of the horizontal R.S.S. field with a standard error of estimate in the order of 5 db. Also, it has been found that the maximum effective radiated field to be expected in these directions of suppression is approximately equal to the theoretical field in the pertinent direction in quadrature with 25% of the horizontal R.S.S. field.

TABLE I

Stations Employed in the Close-In Directional Antenna Suppression Study

CALL	FREQ. (kc)	Erms (mv/m)	Emax. (mv/m)	Erss (mv/m)
KCMO	810	600	1380	670
WINS	1010	1630	3340	2080
WIBG	990	660	1450	1172
WBT	1110	1590	2680	1625
WXKW	850	580	1530	1998
KOAM	860	418	680	424
WCTT Corbin, Ky. 1.0 v. DAN.	680	175	298	208
KIDO	630	434	738	448
KING	1090	1655	2660	1618
WMAY	970	153	310	235
WTVH	1590	214	400	269
WLEX	1300	200	408	298
KSJO	1590	156	220	156

KING

TABLE II

Stations Employed in the Skywave Antenna Suppression Study

CALL	FREQ. (kc)	Erms (mv/m)	Emax (mv/m)	Erss (mv/m)
WBAL	1090	1600	2600	1655
KOMA	1520	1700	3000	1930
WGBS	710	600	970	534
WMAZ	940	622	1500	1595
WHB	710	400	850	405
WKOW	1070	405	1200	524
KOAM	860	418	680	424
KABC	680	601	1450	724
KCMO	810	600	1380	670
WWVA	1170	1600	2550	1570
WXKW	850	570	1440	963
WNAO	850	394	940	1223
WLAC Nashville	1510	1600	2650	2018
KXEL	1540	1700	2350	1678

TABLE III

List of Receiving Locations in Skywave Antenna Suppression Study

Allegan, Michigan

Atlanta, Georgia

Baltimore, Maryland

Chicago, Illinois

Cincinnati, Ohio

Cleveland, Ohio

Dallas, Texas

Des Moines, Iowa

Detroit, Michigan

Grand Island, Nebraska

Nashville, Tennessee

Kingsville, Texas

Portland, Oregon

Salt Lake City, Utah

Rochester, New York

Richmond, Florida

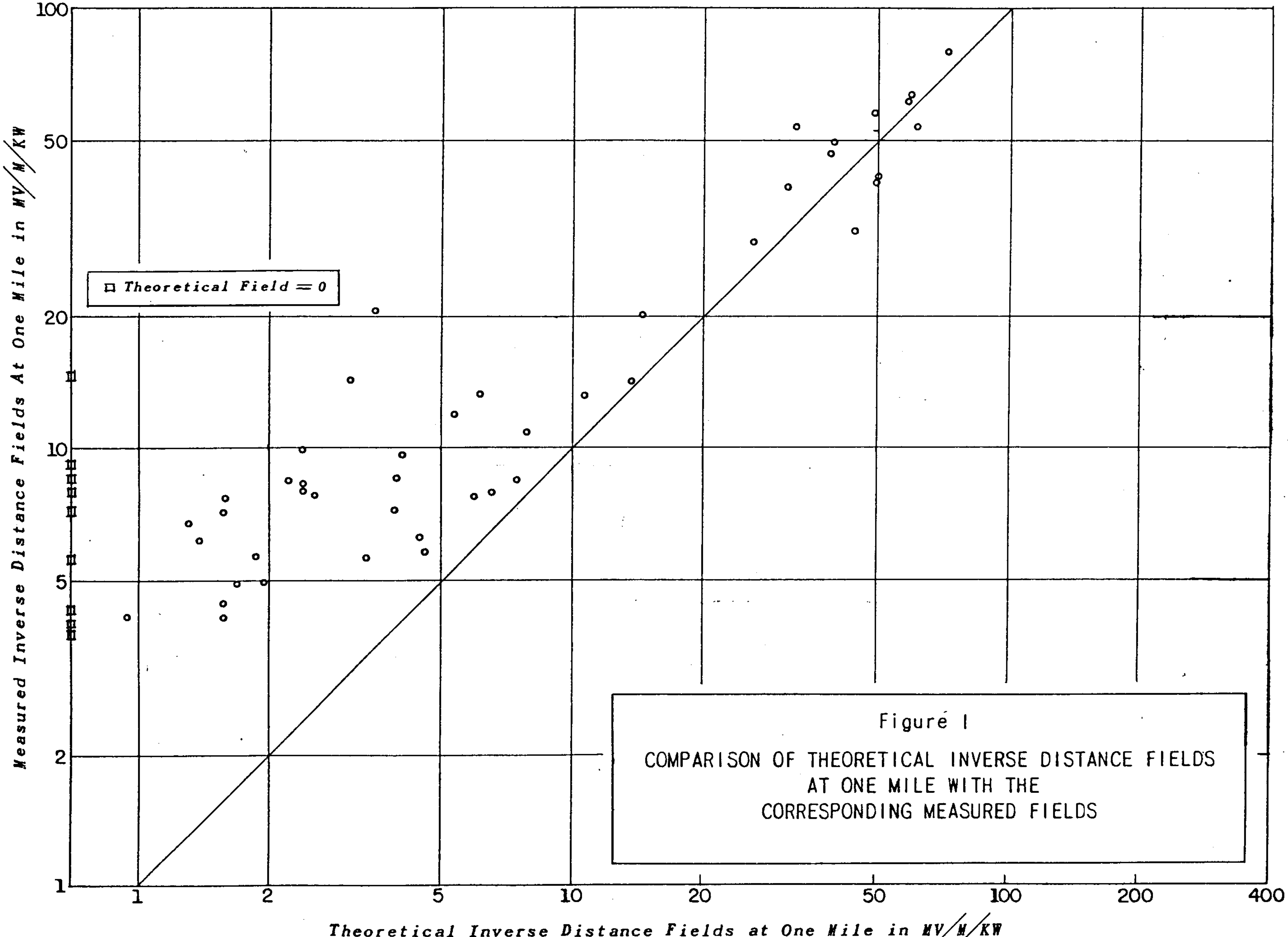


Figure I

COMPARISON OF THEORETICAL INVERSE DISTANCE FIELDS AT ONE MILE WITH THE CORRESPONDING MEASURED FIELDS

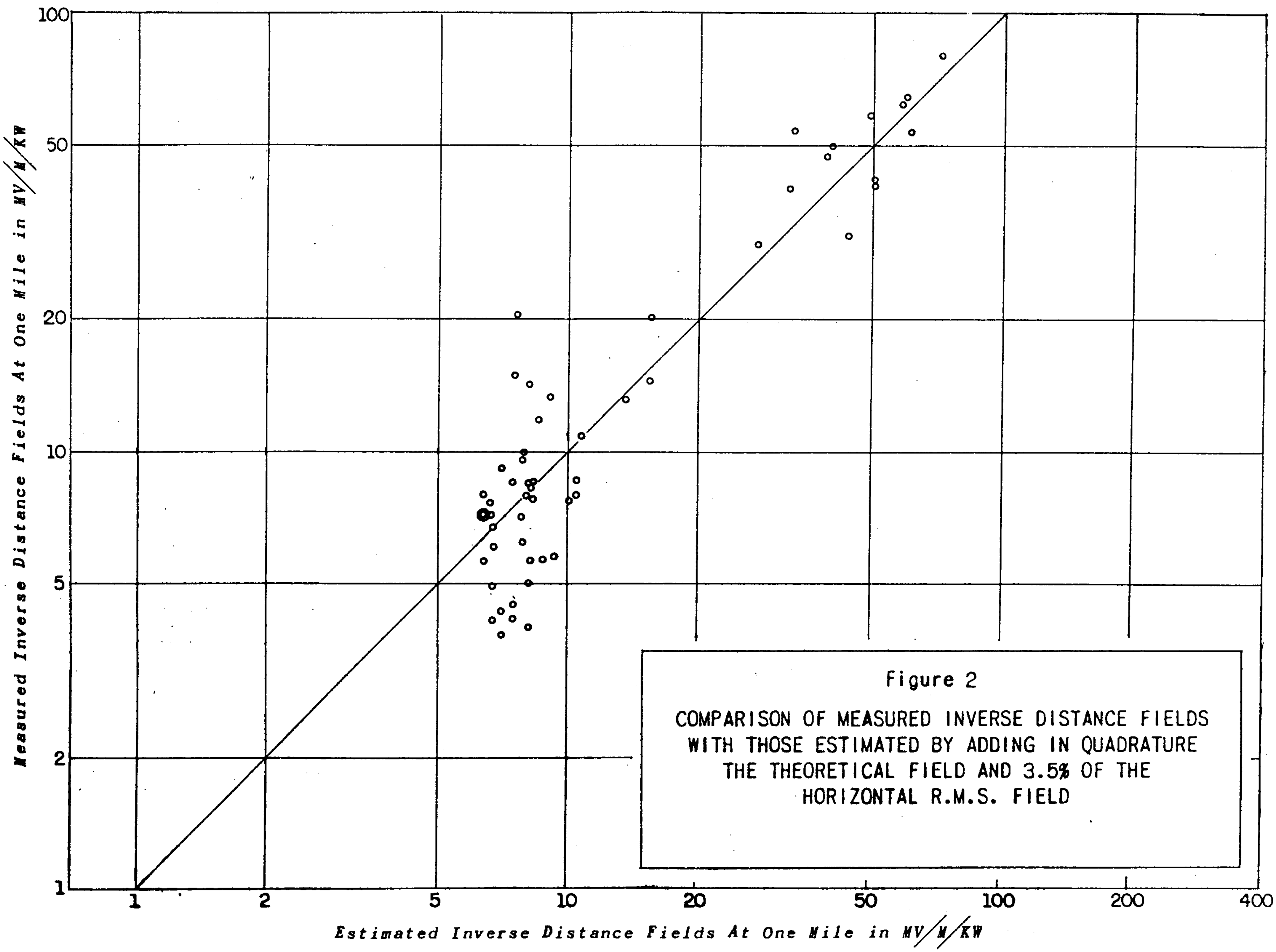


Figure 2

COMPARISON OF MEASURED INVERSE DISTANCE FIELDS WITH THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AND 3.5% OF THE HORIZONTAL R.M.S. FIELD

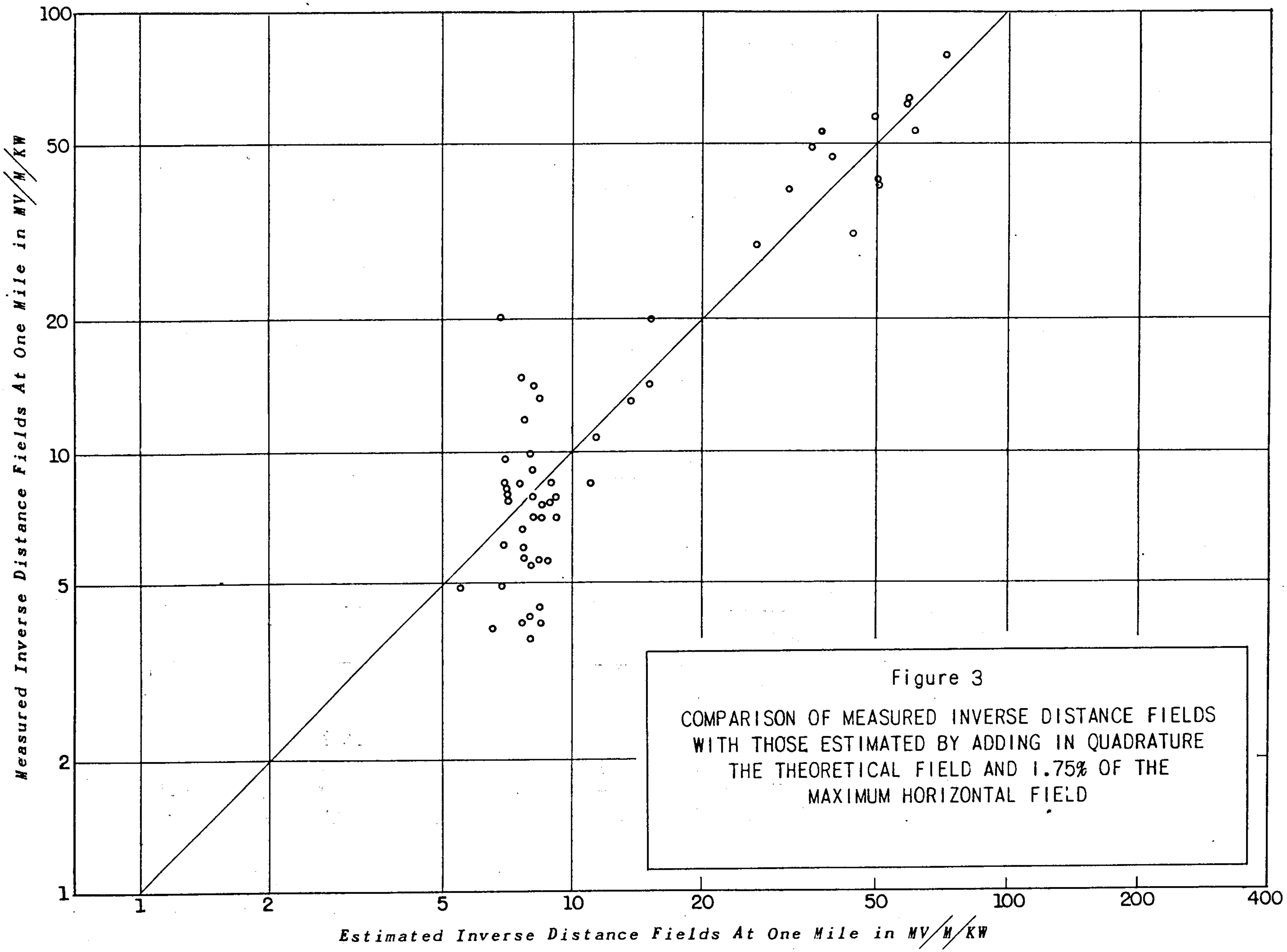


Figure 3

COMPARISON OF MEASURED INVERSE DISTANCE FIELDS WITH THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AND 1.75% OF THE MAXIMUM HORIZONTAL FIELD

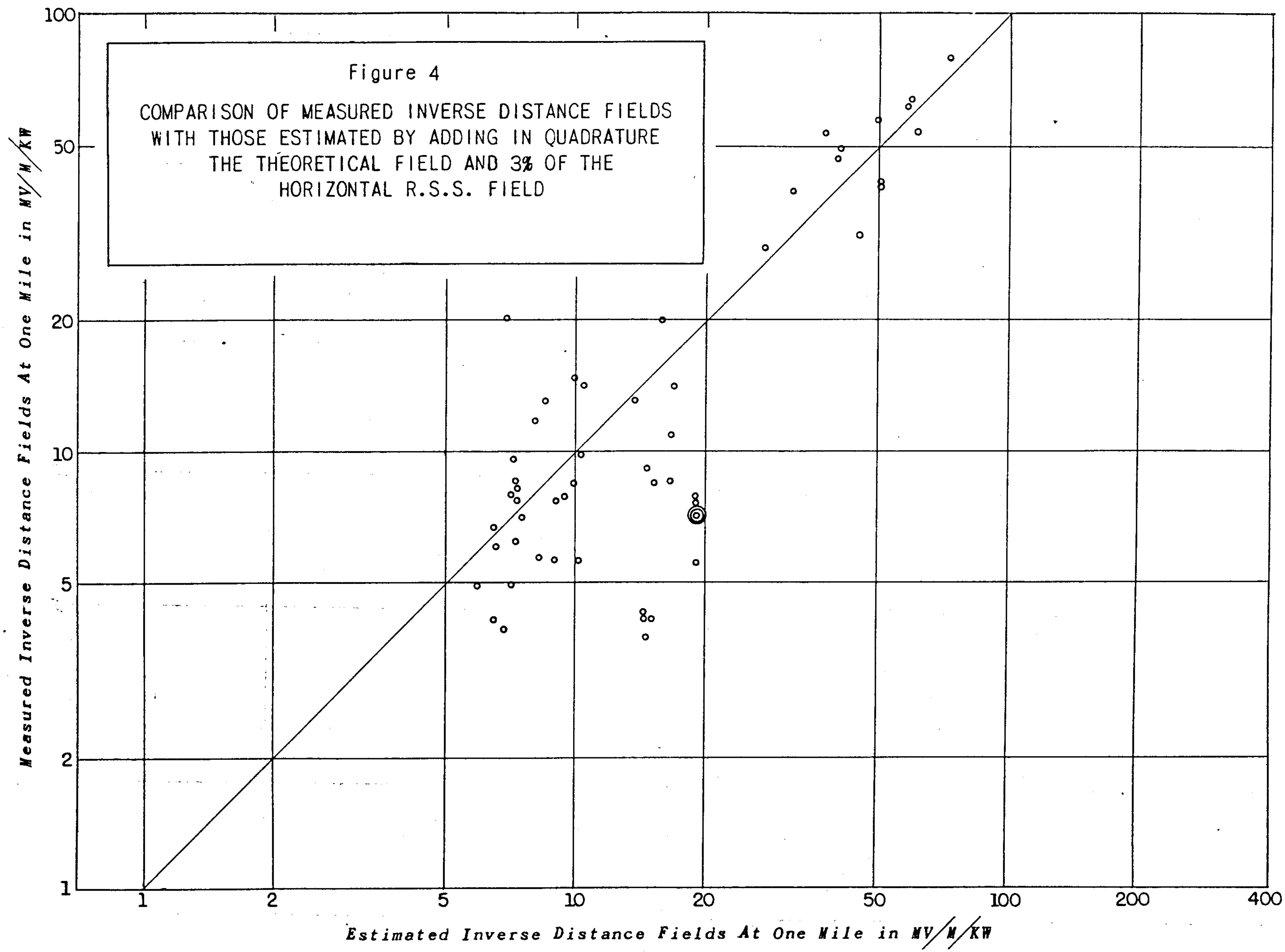


Figure 4
COMPARISON OF MEASURED INVERSE DISTANCE FIELDS
WITH THOSE ESTIMATED BY ADDING IN QUADRATURE
THE THEORETICAL FIELD AND 3% OF THE
HORIZONTAL R.S.S. FIELD
100
50
20
10
5
2
1
1
2
5
10
20
50
100
200
400
Measured Inverse Distance Fields At One Mile in MV/M/KW
Estimated Inverse Distance Fields At One Mile in MV/M/KW

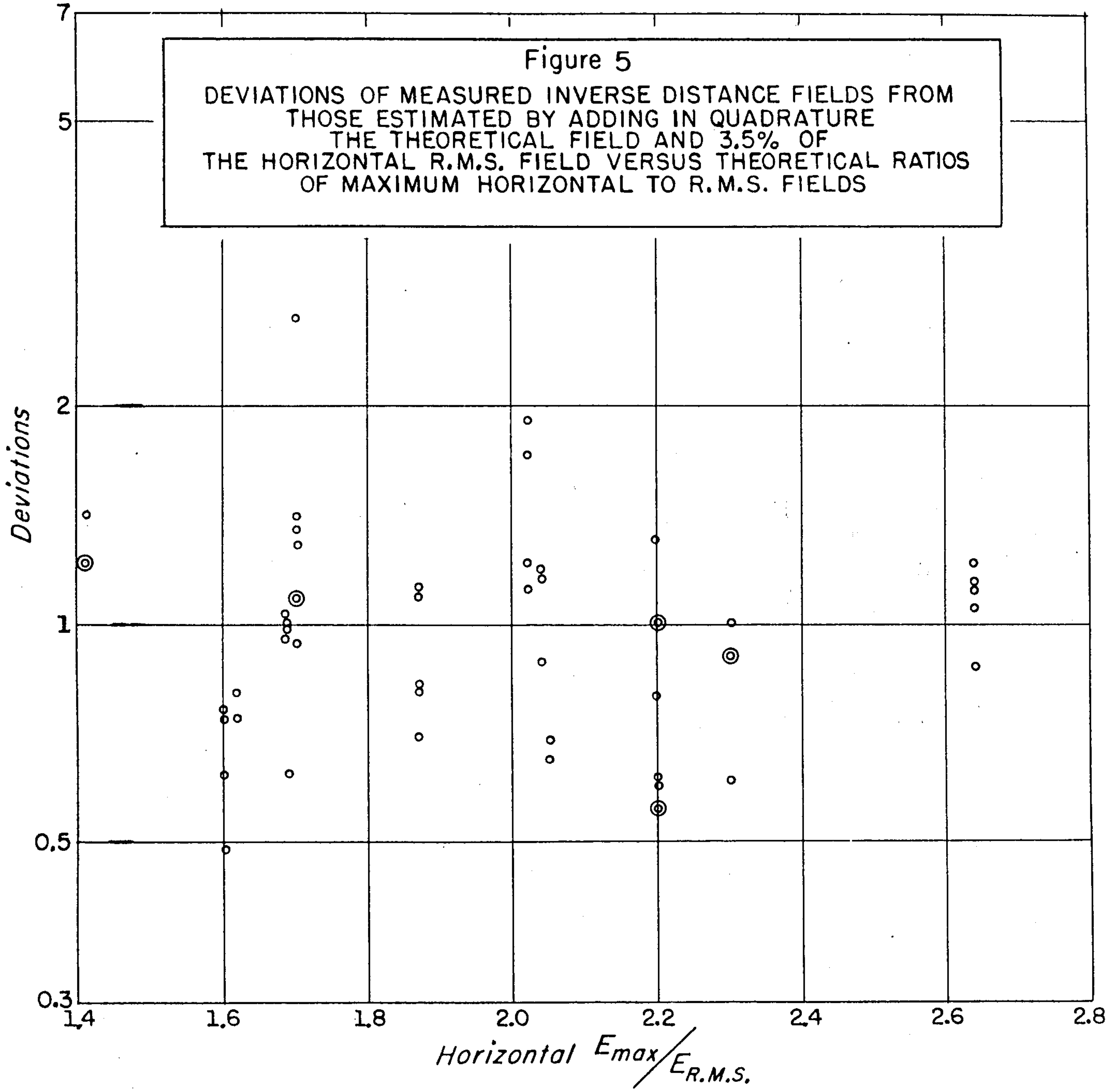


Figure 5
DEVIATIONS OF MEASURED INVERSE DISTANCE FIELDS FROM THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AND 3.5% OF THE HORIZONTAL R.M.S. FIELD VERSUS THEORETICAL RATIOS OF MAXIMUM HORIZONTAL TO R.M.S. FIELDS
Deviations
7
5
2
1
0.5
0.3
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
Horizontal Emax/ER.M.S.

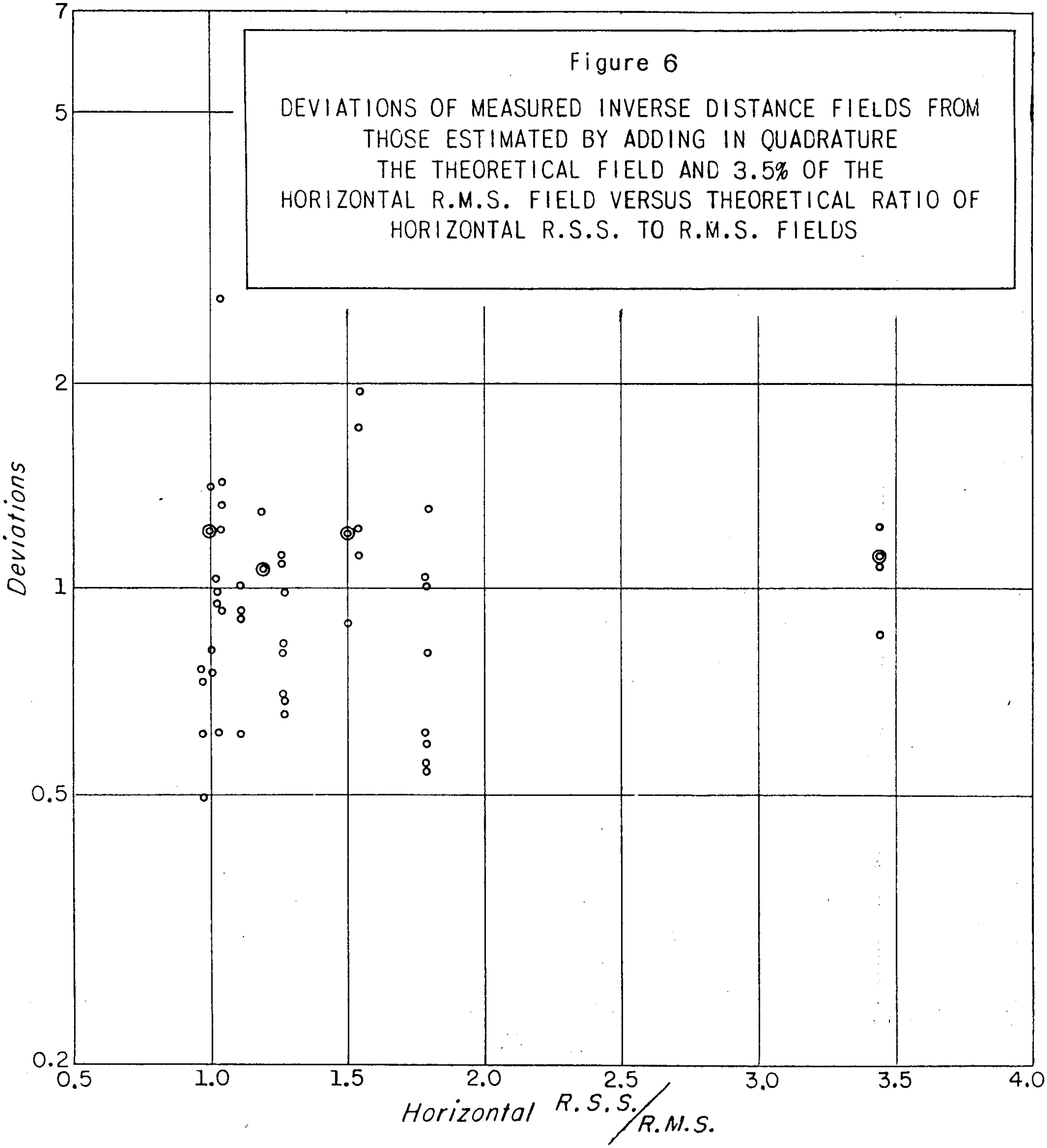


Figure 6
DEVIATIONS OF MEASURED INVERSE DISTANCE FIELDS FROM THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AND 3.5% OF THE HORIZONTAL R.M.S. FIELD VERSUS THEORETICAL RATIO OF HORIZONTAL R.S.S. TO R.M.S. FIELDS
Deviations
7
5
2
1
0.5
0.2
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Horizontal R.S.S./R.M.S.

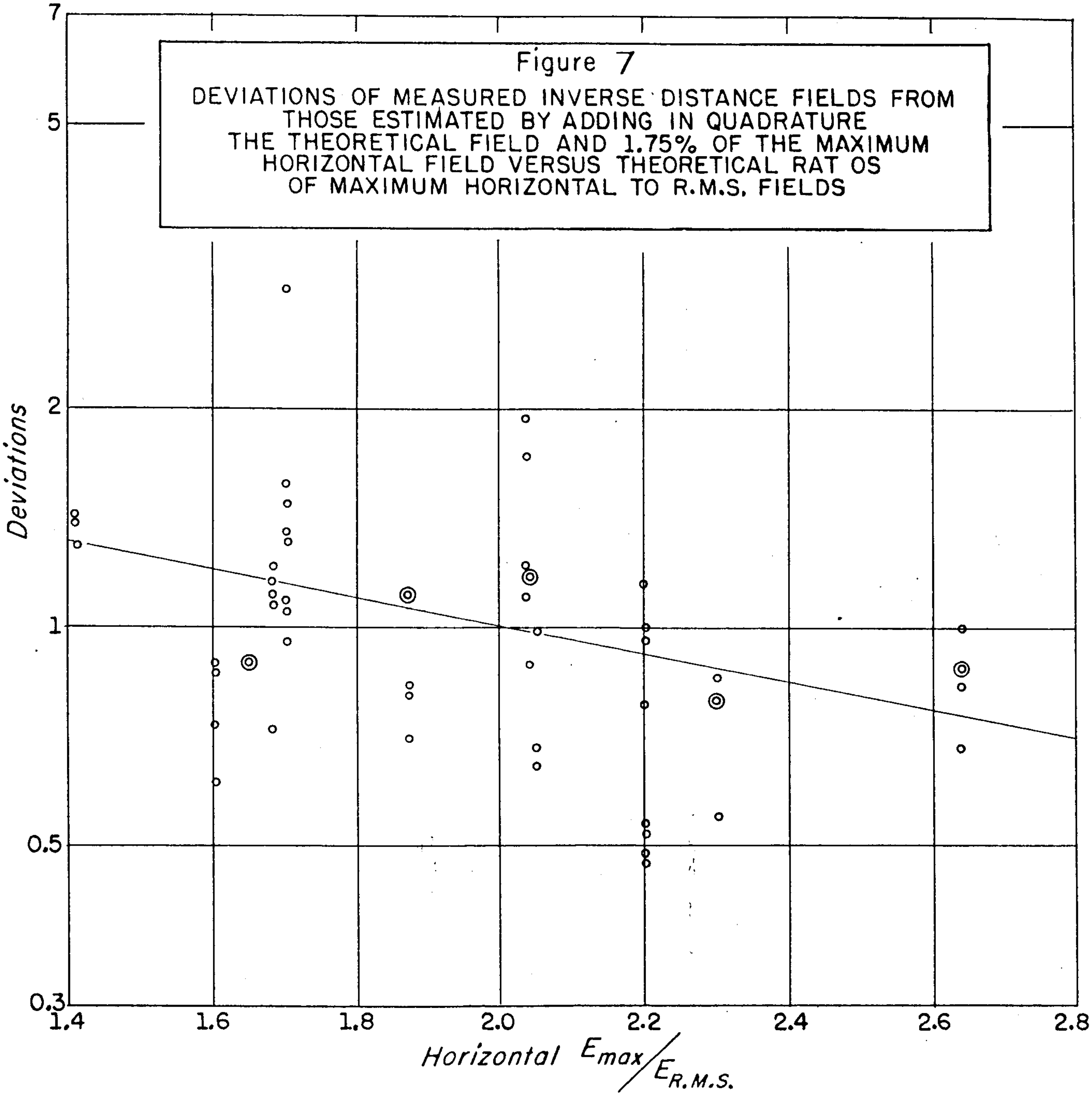


Figure 7
DEVIATIONS OF MEASURED INVERSE DISTANCE FIELDS FROM THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AND 1.75% OF THE MAXIMUM HORIZONTAL FIELD VERSUS THEORETICAL RAT OS OF MAXIMUM HORIZONTAL TO R.M.S. FIELDS
Deviations
7
5
2
1
0.5
0.3
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
Horizontal Emax/ER.M.S.

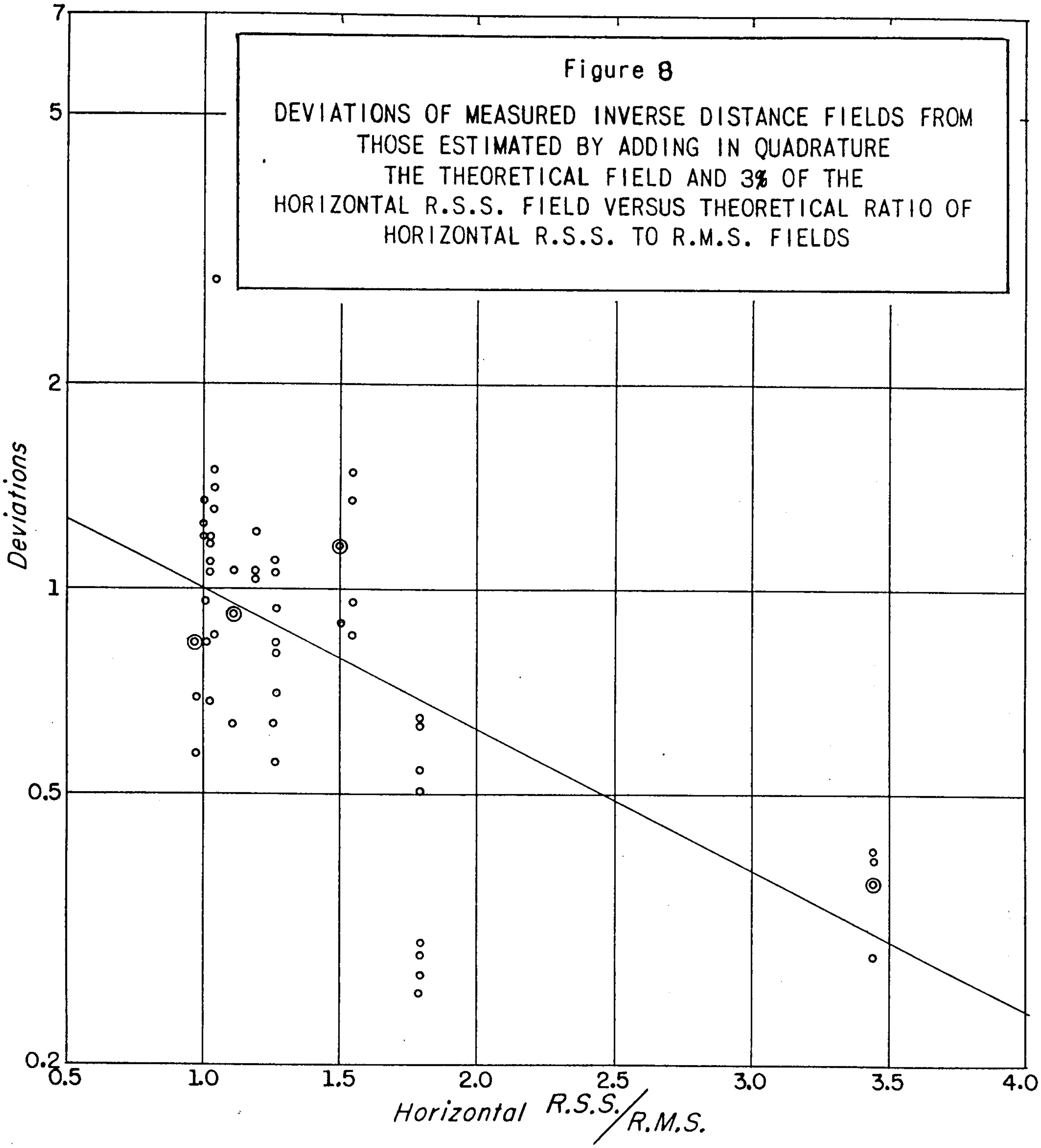


Figure 8
DEVIATIONS OF MEASURED INVERSE DISTANCE FIELDS FROM THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AND 3% OF THE HORIZONTAL R.S.S. FIELD VERSUS THEORETICAL RATIO OF HORIZONTAL R.S.S. TO R.M.S. FIELDS
Deviations
7
5
2
1
0.5
0.2
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Horizontal R.S.S./R.M.S.

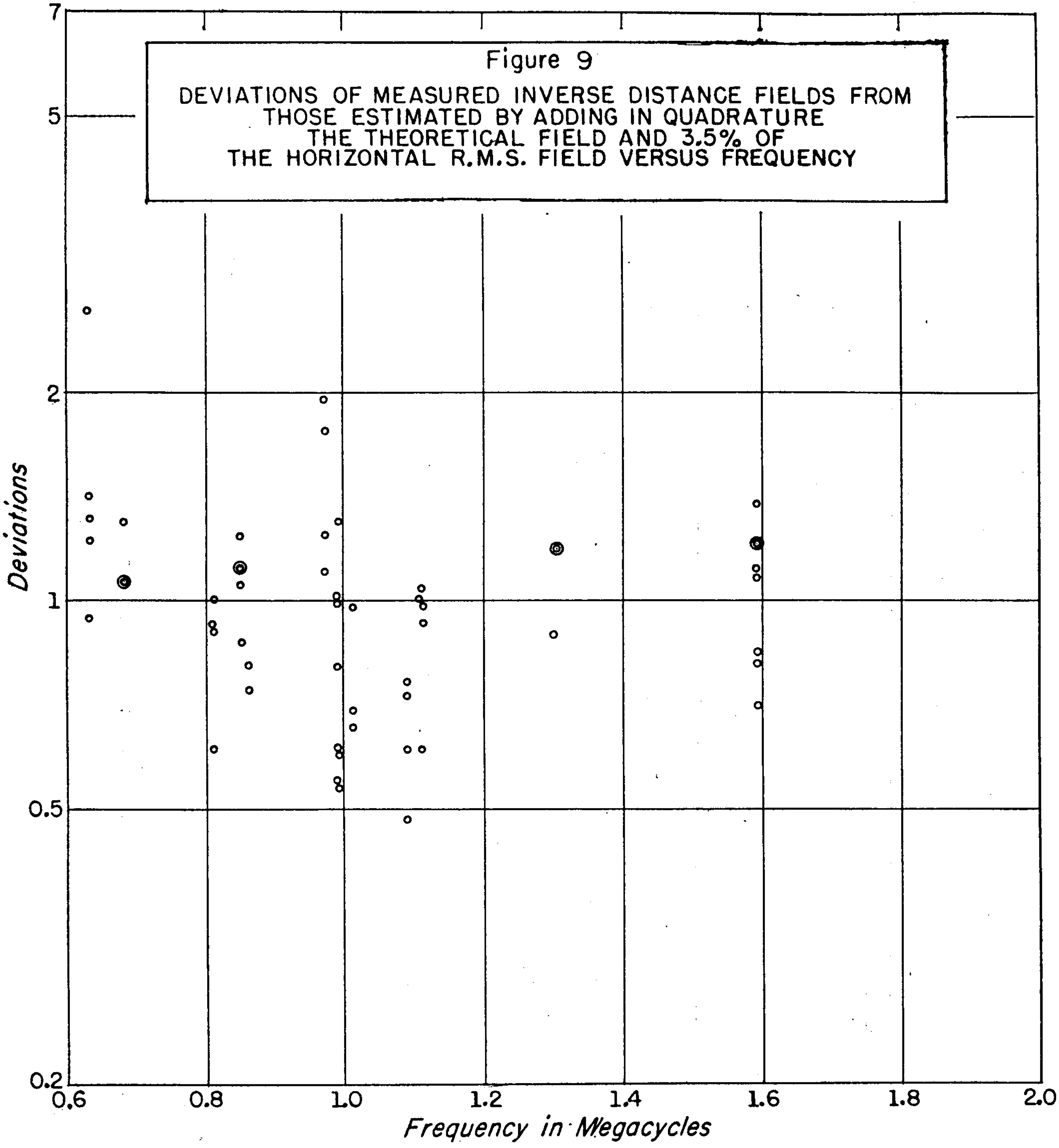


Figure 9
DEVIATIONS OF MEASURED INVERSE DISTANCE FIELDS FROM THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AND 3.5% OF THE HORIZONTAL R.M.S. FIELD VERSUS FREQUENCY
Deviations
7
5
2
1
0.5
0.2
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Frequency in Megacycles

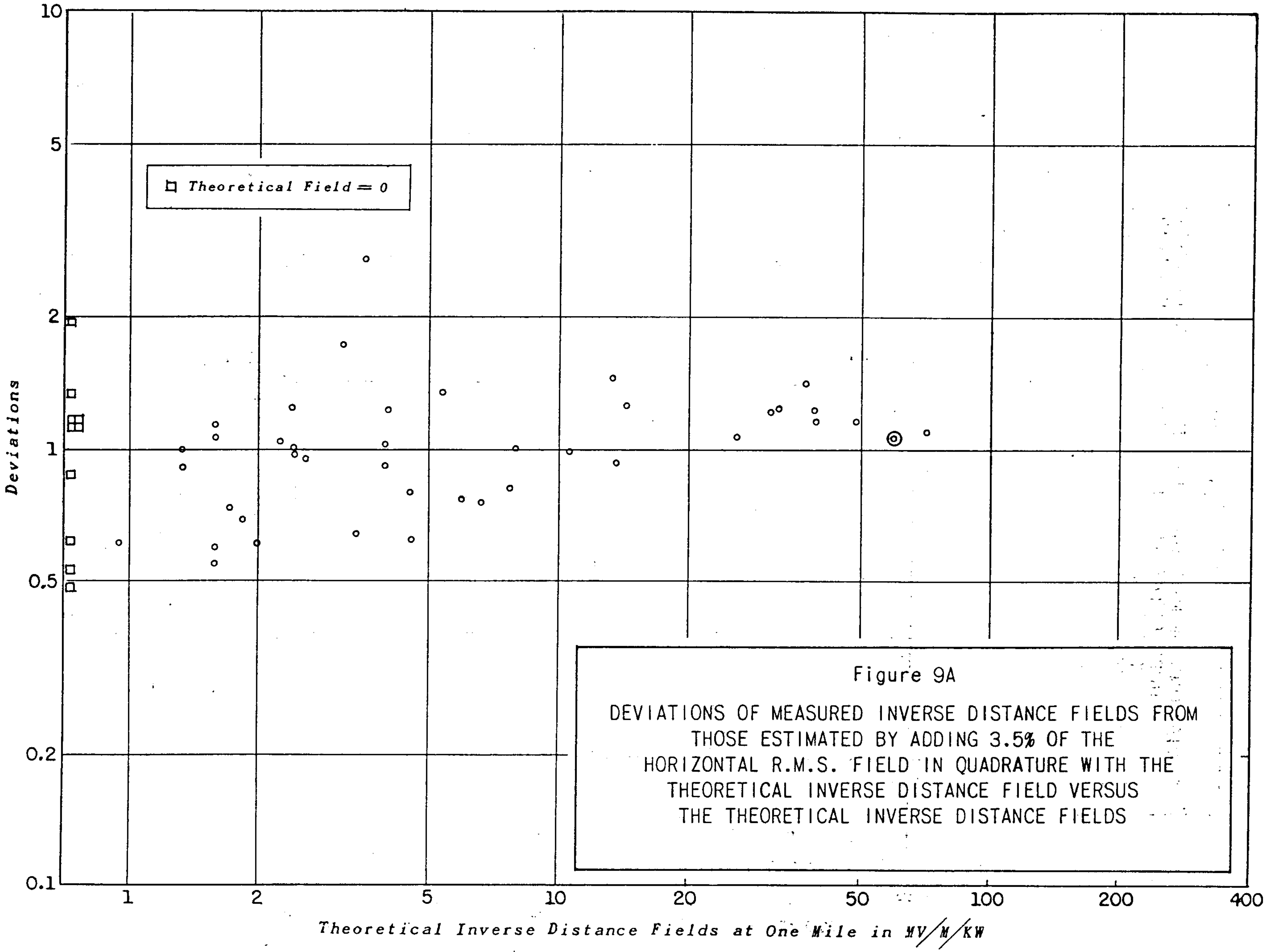


Figure 9A

DEVIATIONS OF MEASURED INVERSE DISTANCE FIELDS FROM THOSE ESTIMATED BY ADDING 3.5% OF THE HORIZONTAL R.M.S. FIELD IN QUADRATURE WITH THE THEORETICAL INVERSE DISTANCE FIELD VERSUS THE THEORETICAL INVERSE DISTANCE FIELDS

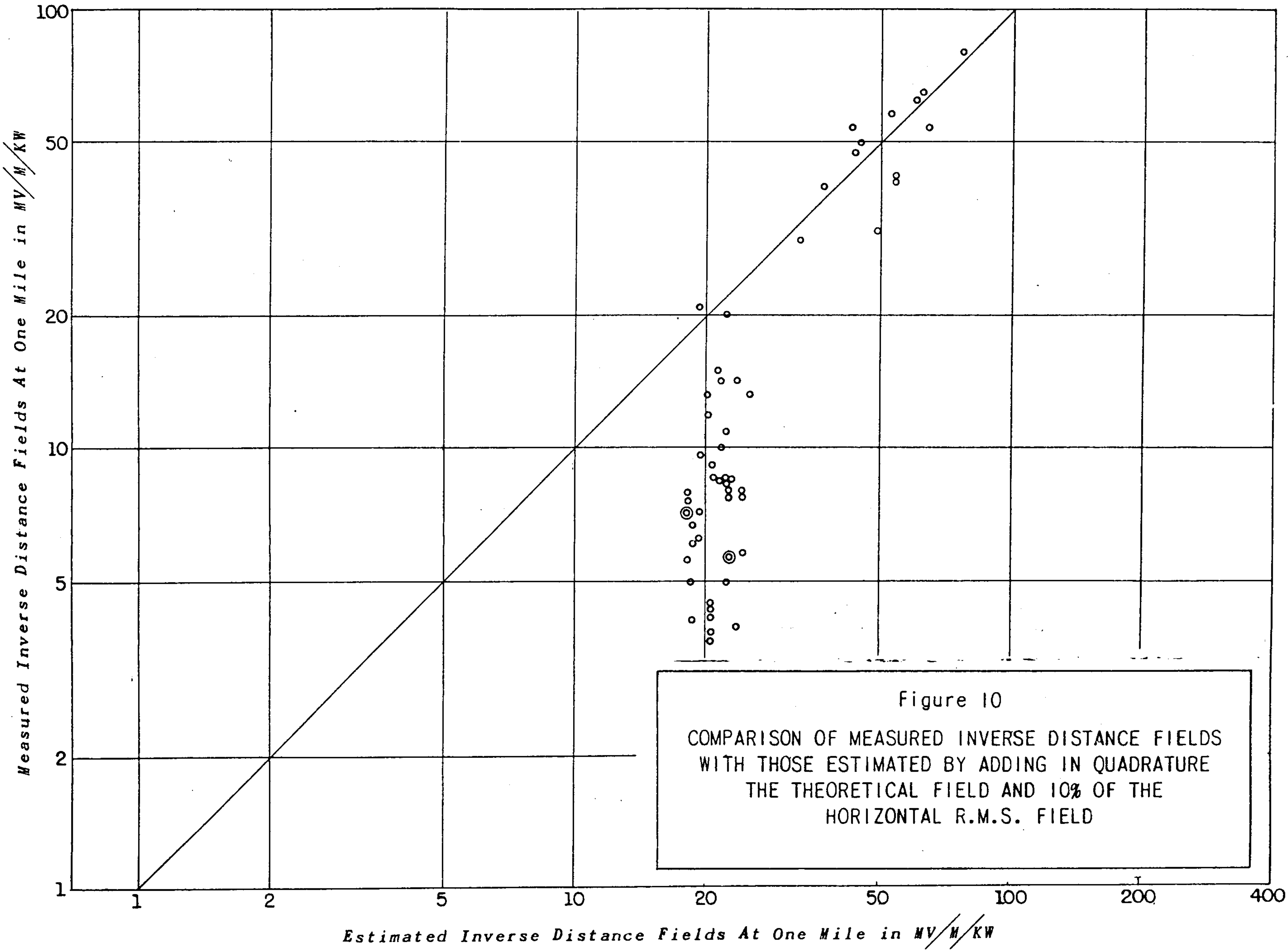


Figure 10

COMPARISON OF MEASURED INVERSE DISTANCE FIELDS WITH THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AND 10% OF THE HORIZONTAL R.M.S. FIELD

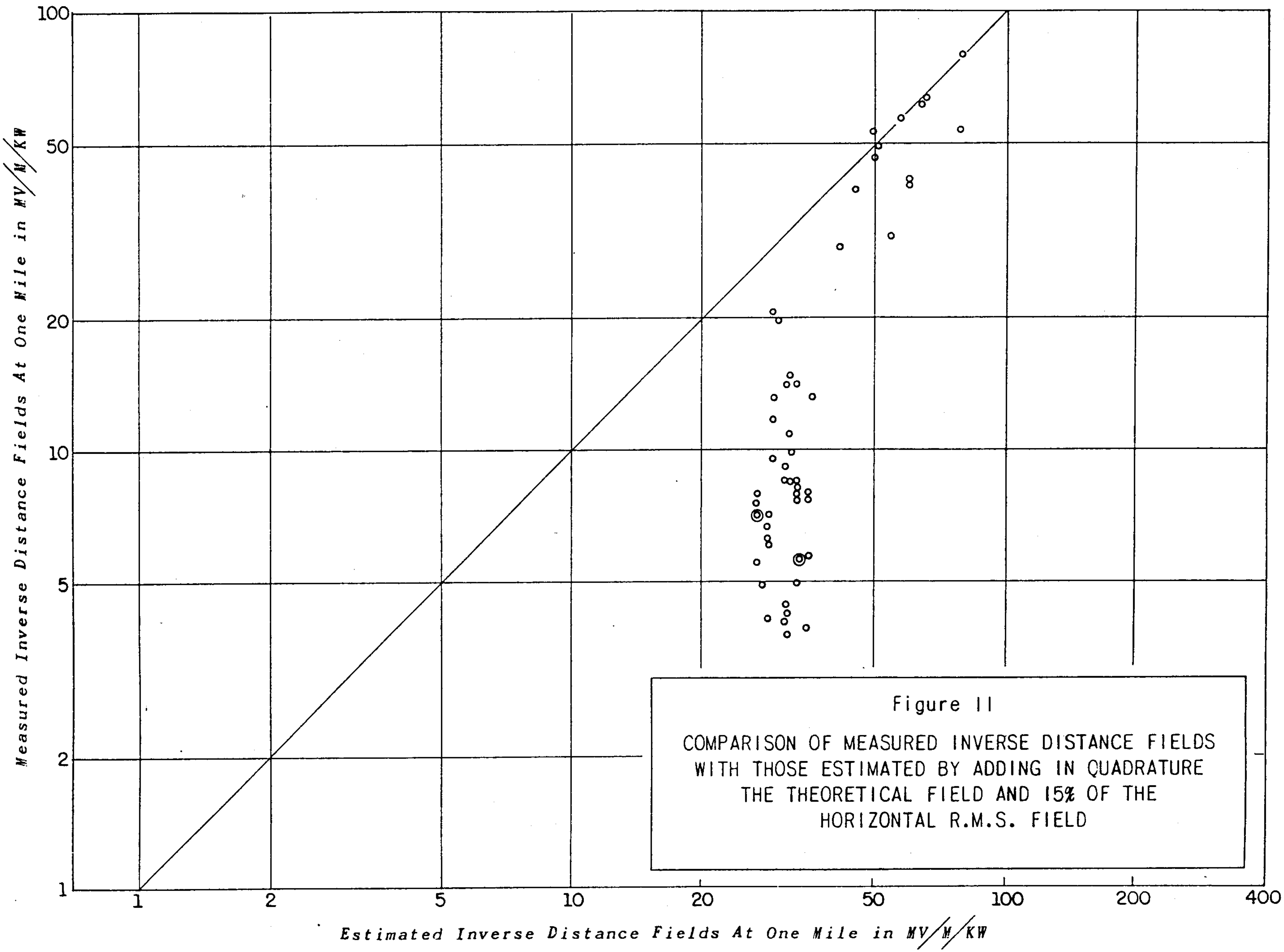


Figure 11

COMPARISON OF MEASURED INVERSE DISTANCE FIELDS WITH THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AND 15% OF THE HORIZONTAL R.M.S. FIELD

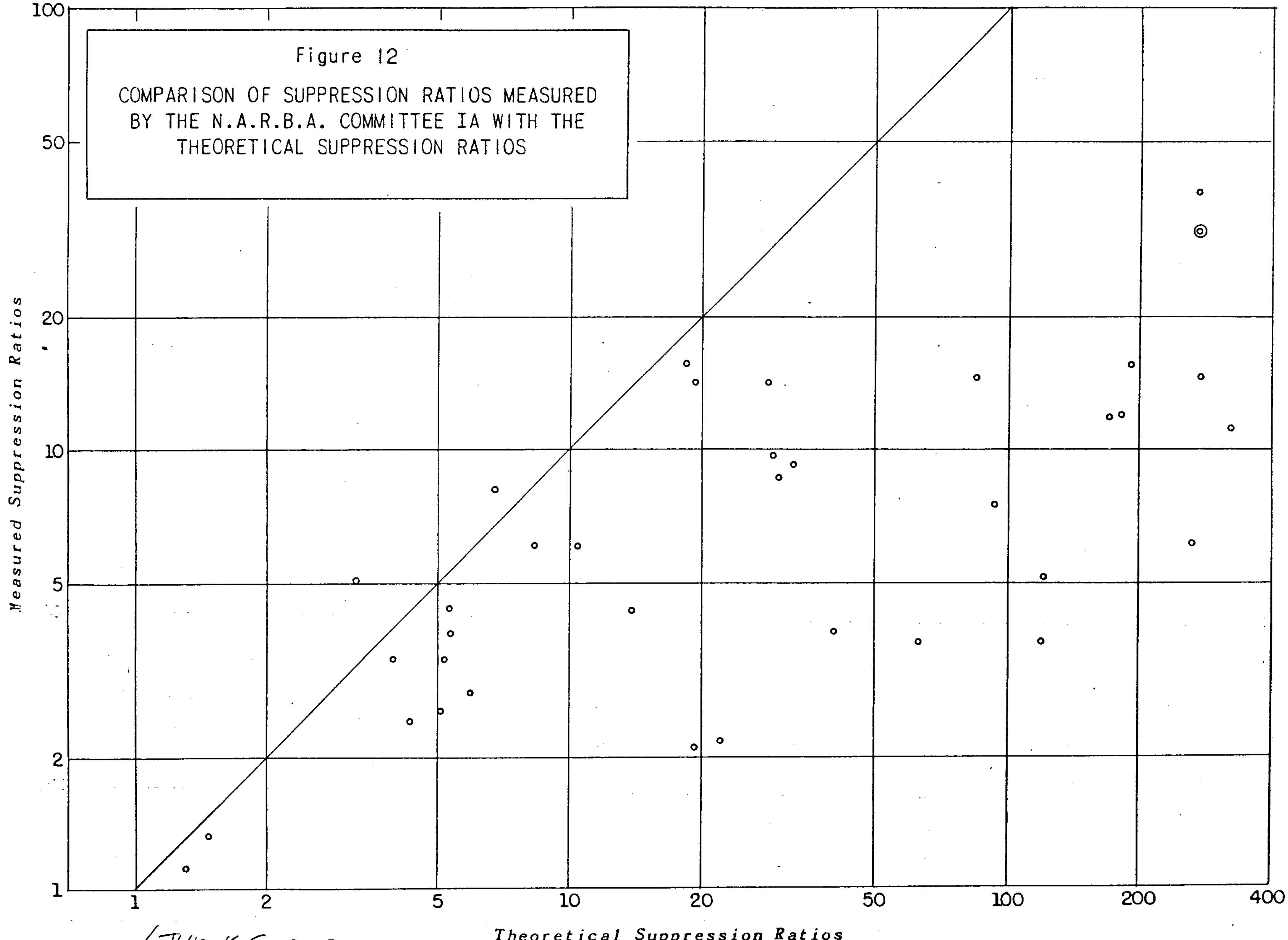


Figure 12

COMPARISON OF SUPPRESSION RATIOS MEASURED BY THE N.A.R.B.A. COMMITTEE IA WITH THE THEORETICAL SUPPRESSION RATIOS

(THIS IS EVIDENTLY DA/NONDA AND LARGE (>100) NUMBERS EVIDENTLY RESULT FROM LOW NITE POWERS)

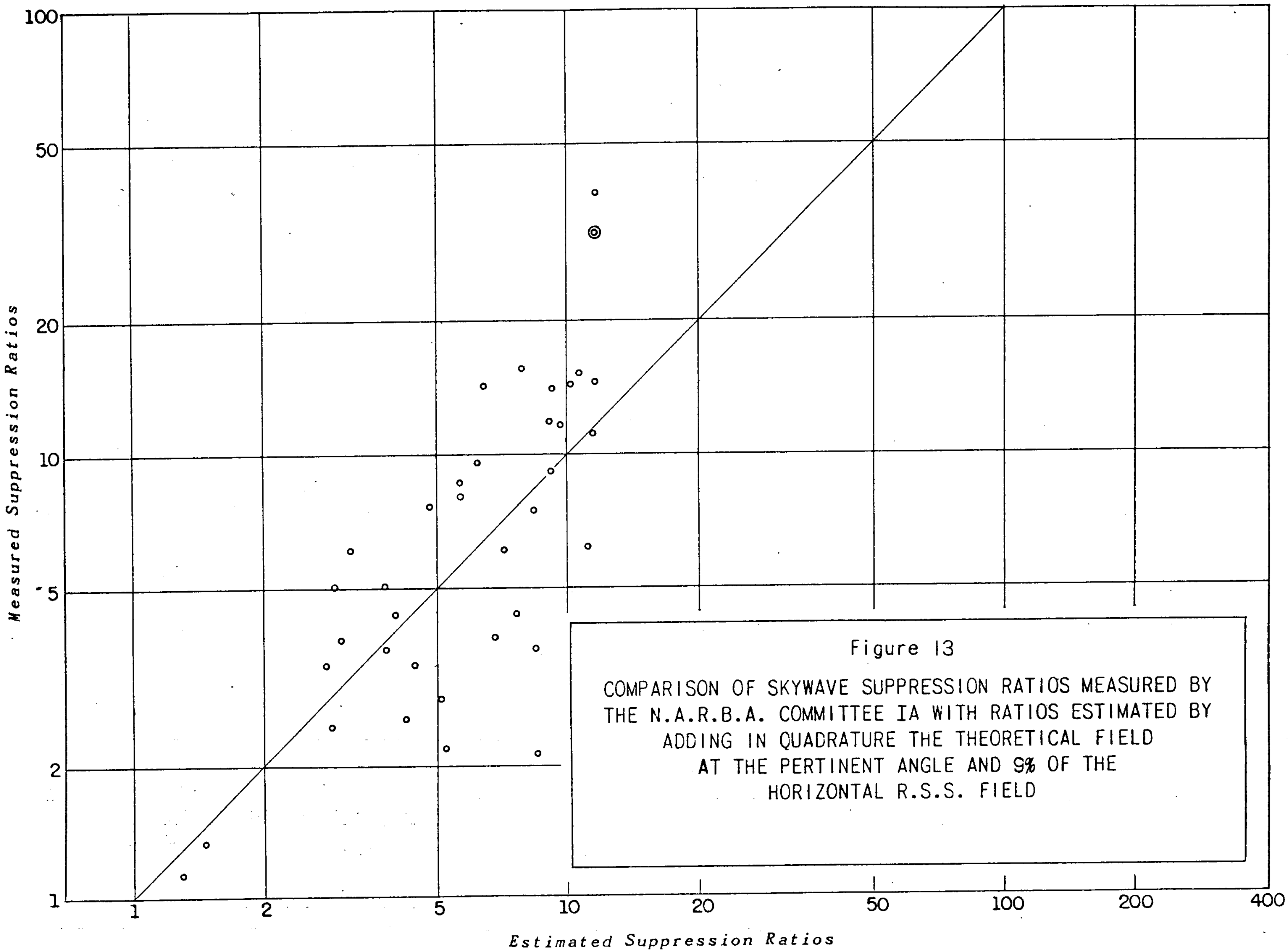


Figure 13

COMPARISON OF SKYWAVE SUPPRESSION RATIOS MEASURED BY THE N.A.R.B.A. COMMITTEE IA WITH RATIOS ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AT THE PERTINENT ANGLE AND 9% OF THE HORIZONTAL R.S.S. FIELD

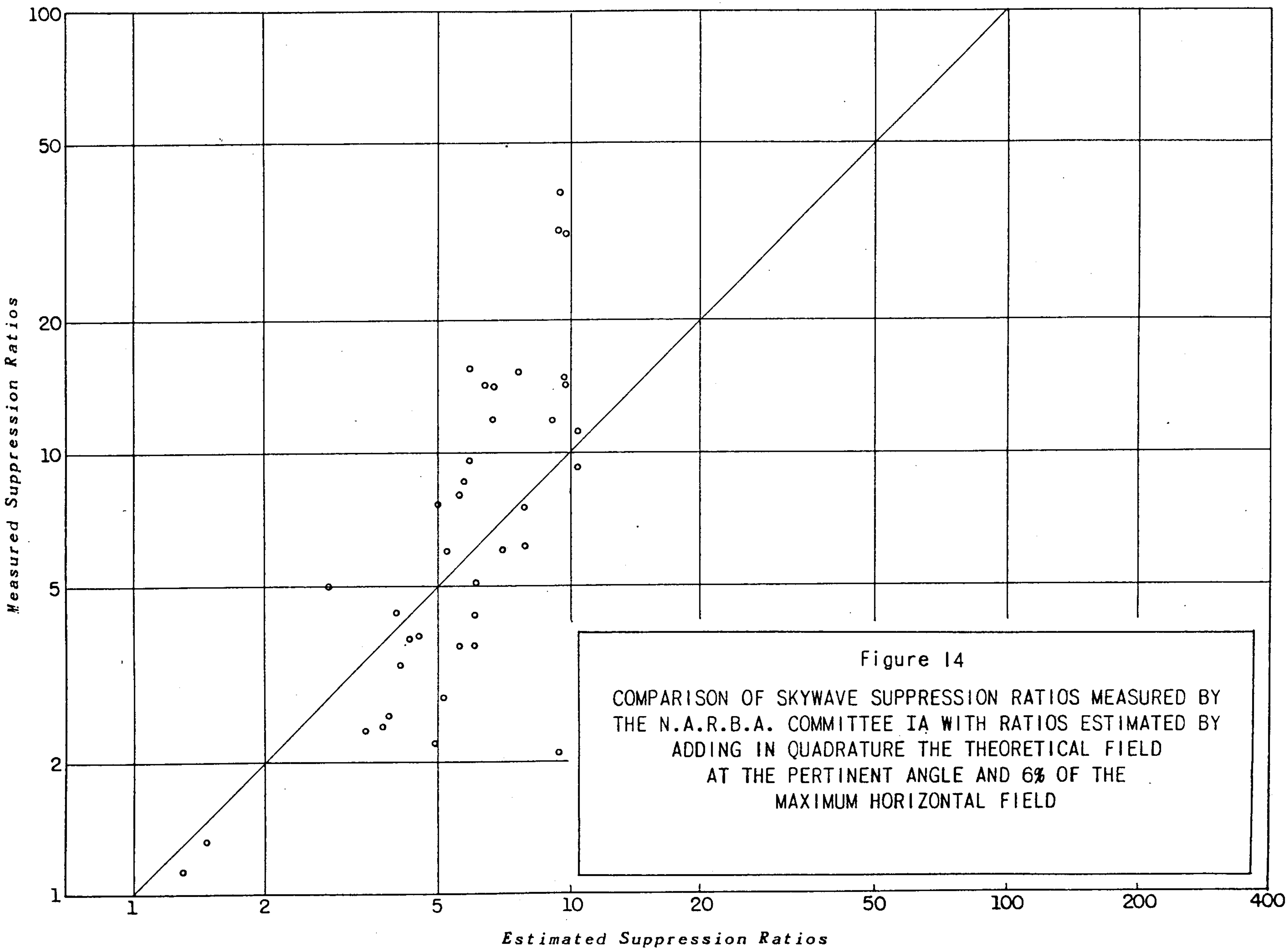


Figure 14

COMPARISON OF SKYWAVE SUPPRESSION RATIOS MEASURED BY THE N.A.R.B.A. COMMITTEE IA WITH RATIOS ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AT THE PERTINENT ANGLE AND 6% OF THE MAXIMUM HORIZONTAL FIELD

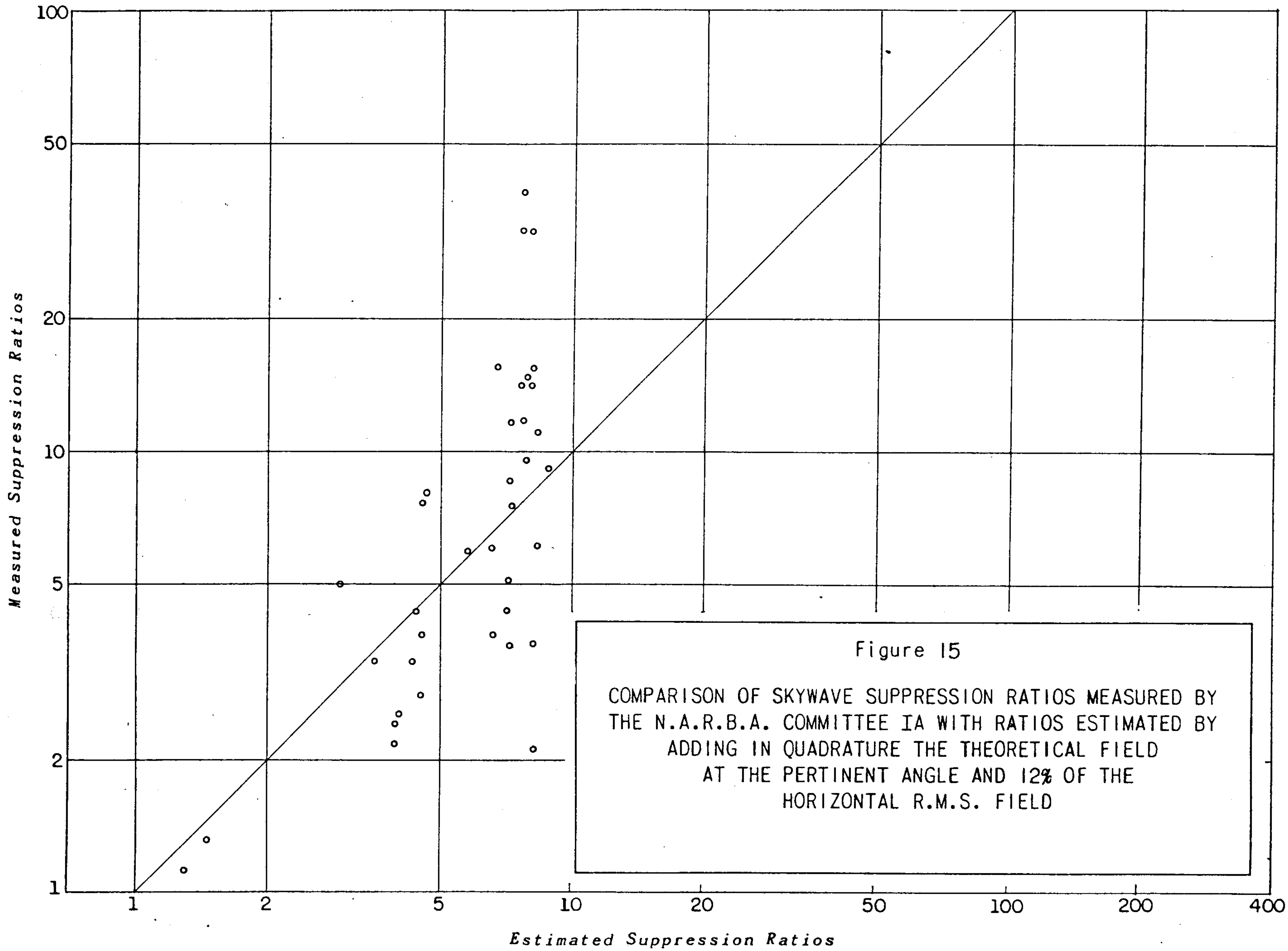


Figure 15

COMPARISON OF SKYWAVE SUPPRESSION RATIOS MEASURED BY THE N.A.R.B.A. COMMITTEE IA WITH RATIOS ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AT THE PERTINENT ANGLE AND 12% OF THE HORIZONTAL R.M.S. FIELD

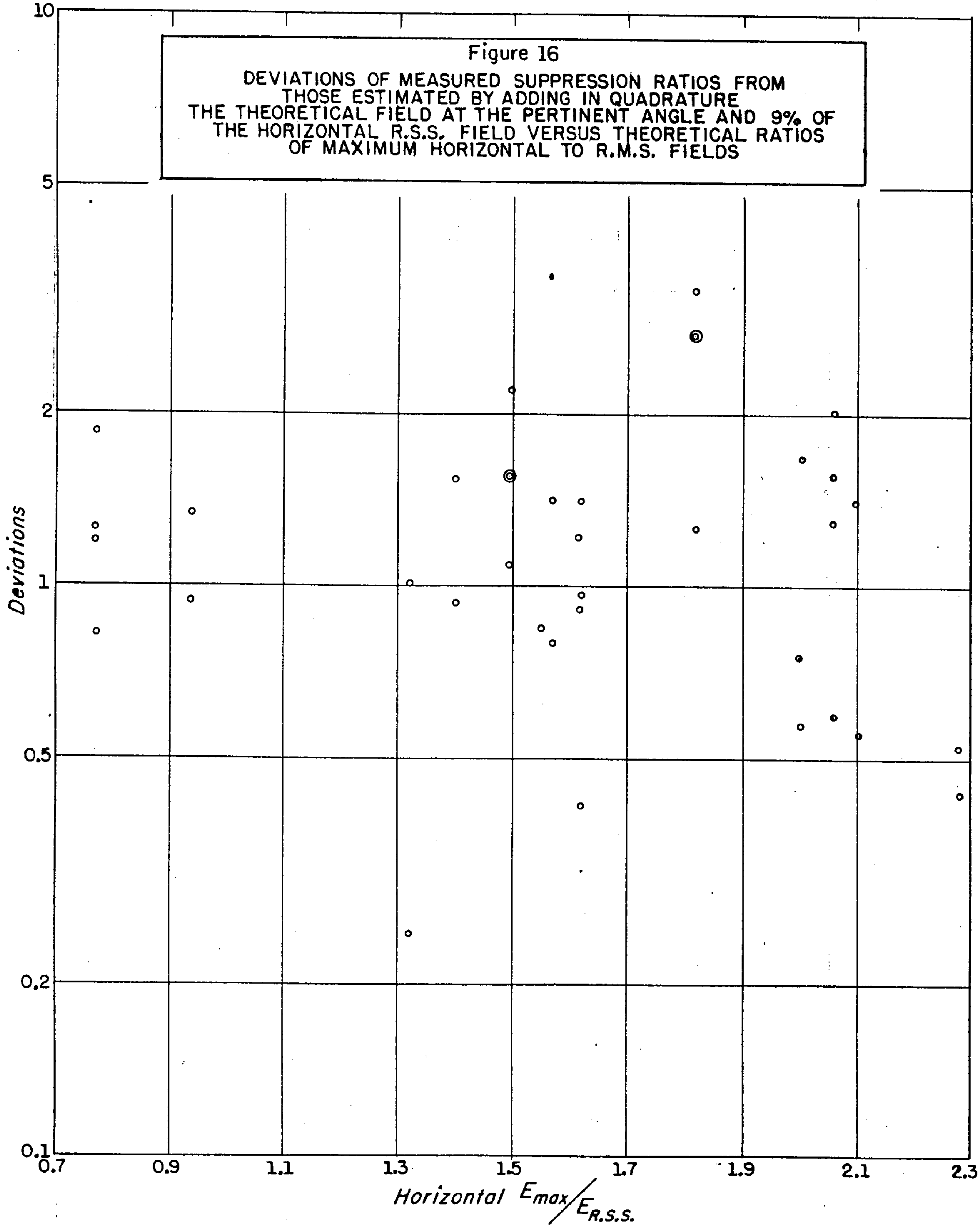


Figure 16
DEVIATIONS OF MEASURED SUPPRESSION RATIOS FROM THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AT THE PERTINENT ANGLE AND 9% OF THE HORIZONTAL R.S.S. FIELD VERSUS THEORETICAL RATIOS OF MAXIMUM HORIZONTAL TO R.M.S. FIELDS
10
5
2
1
0.5
0.2
0.1
Deviations
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
Horizontal Emax/ER.S.S.

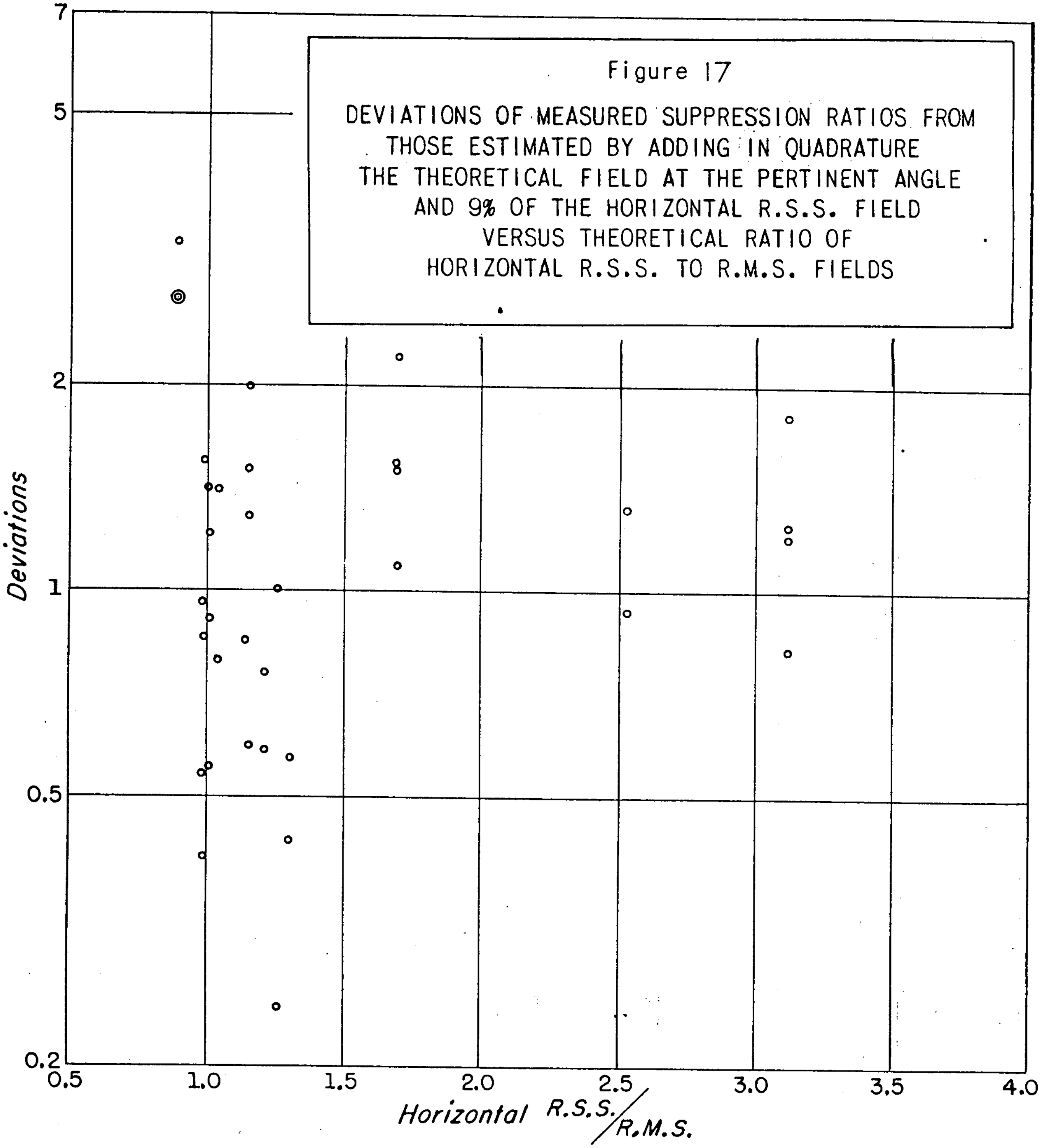


Figure 17
DEVIATIONS OF MEASURED SUPPRESSION RATIOS FROM THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AT THE PERTINENT ANGLE AND 9% OF THE HORIZONTAL R.S.S. FIELD VERSUS THEORETICAL RATIO OF HORIZONTAL R.S.S. TO R.M.S. FIELDS
Deviations
7
5
2
1
0.5
0.2
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Horizontal R.S.S./R.M.S.

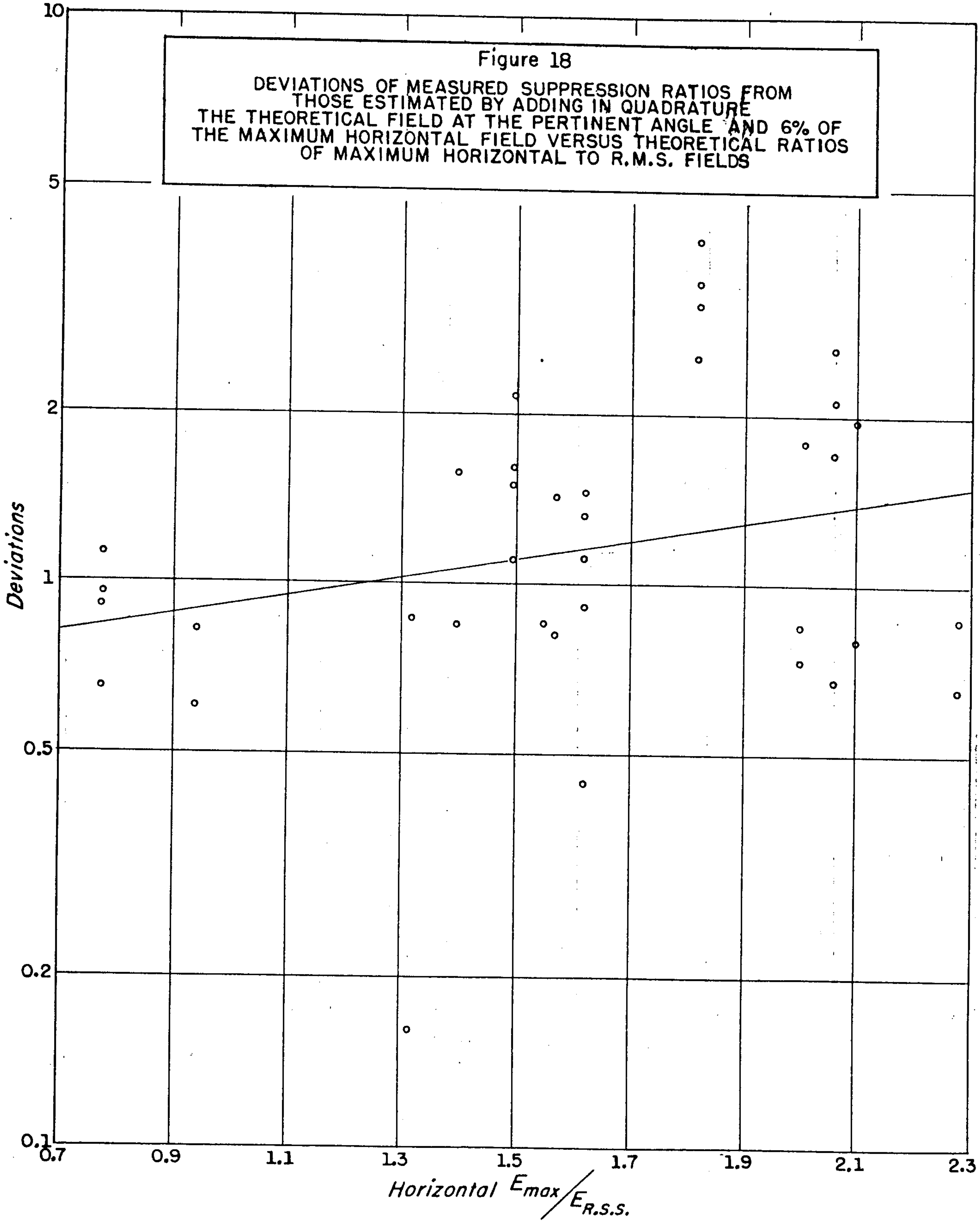


Figure 18

DEVIATIONS OF MEASURED SUPPRESSION RATIOS FROM THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AT THE PERTINENT ANGLE AND 6% OF THE MAXIMUM HORIZONTAL FIELD VERSUS THEORETICAL RATIOS OF MAXIMUM HORIZONTAL TO R.M.S. FIELDS

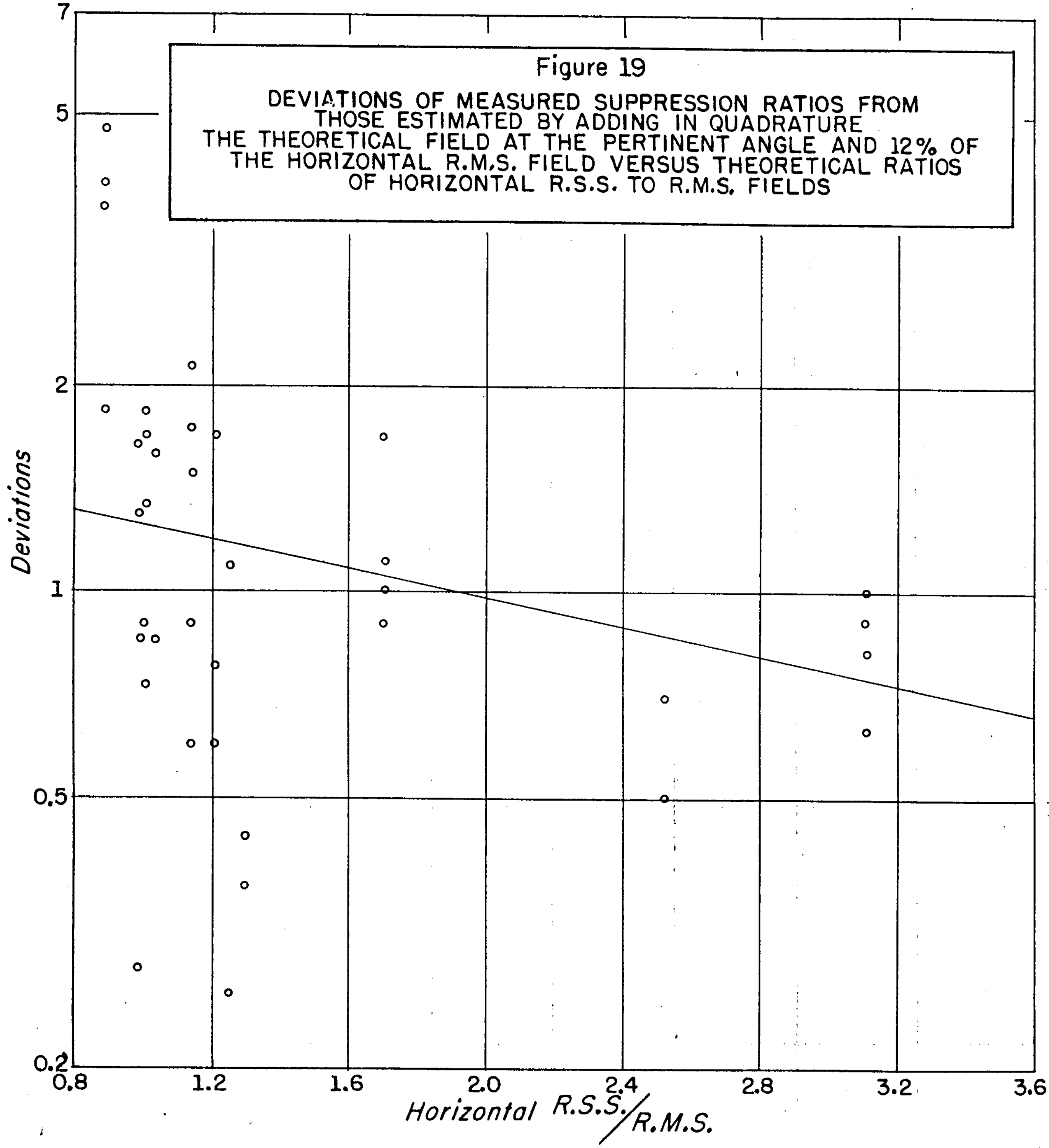


Figure 19
DEVIATIONS OF MEASURED SUPPRESSION RATIOS FROM THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AT THE PERTINENT ANGLE AND 12% OF THE HORIZONTAL R.M.S. FIELD VERSUS THEORETICAL RATIOS OF HORIZONTAL R.S.S. TO R.M.S. FIELDS
Deviations
7
5
2
1
0.5
0.2
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
Horizontal R.S.S./R.M.S.

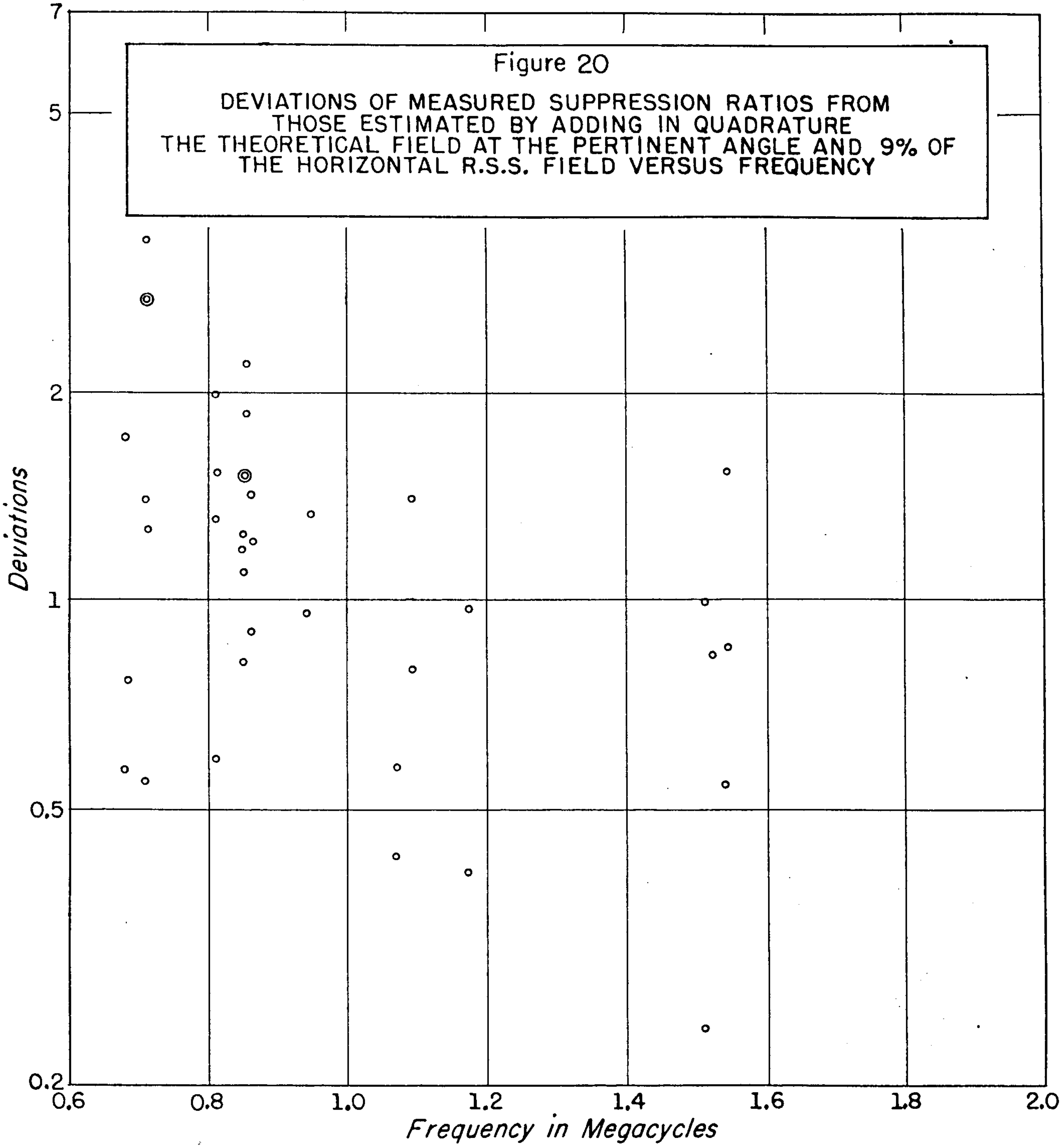


Figure 20
DEVIATIONS OF MEASURED SUPPRESSION RATIOS FROM THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AT THE PERTINENT ANGLE AND 9% OF THE HORIZONTAL R.S.S. FIELD VERSUS FREQUENCY
7
5
2
1
0.5
0.2
Deviations
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Frequency in Megacycles

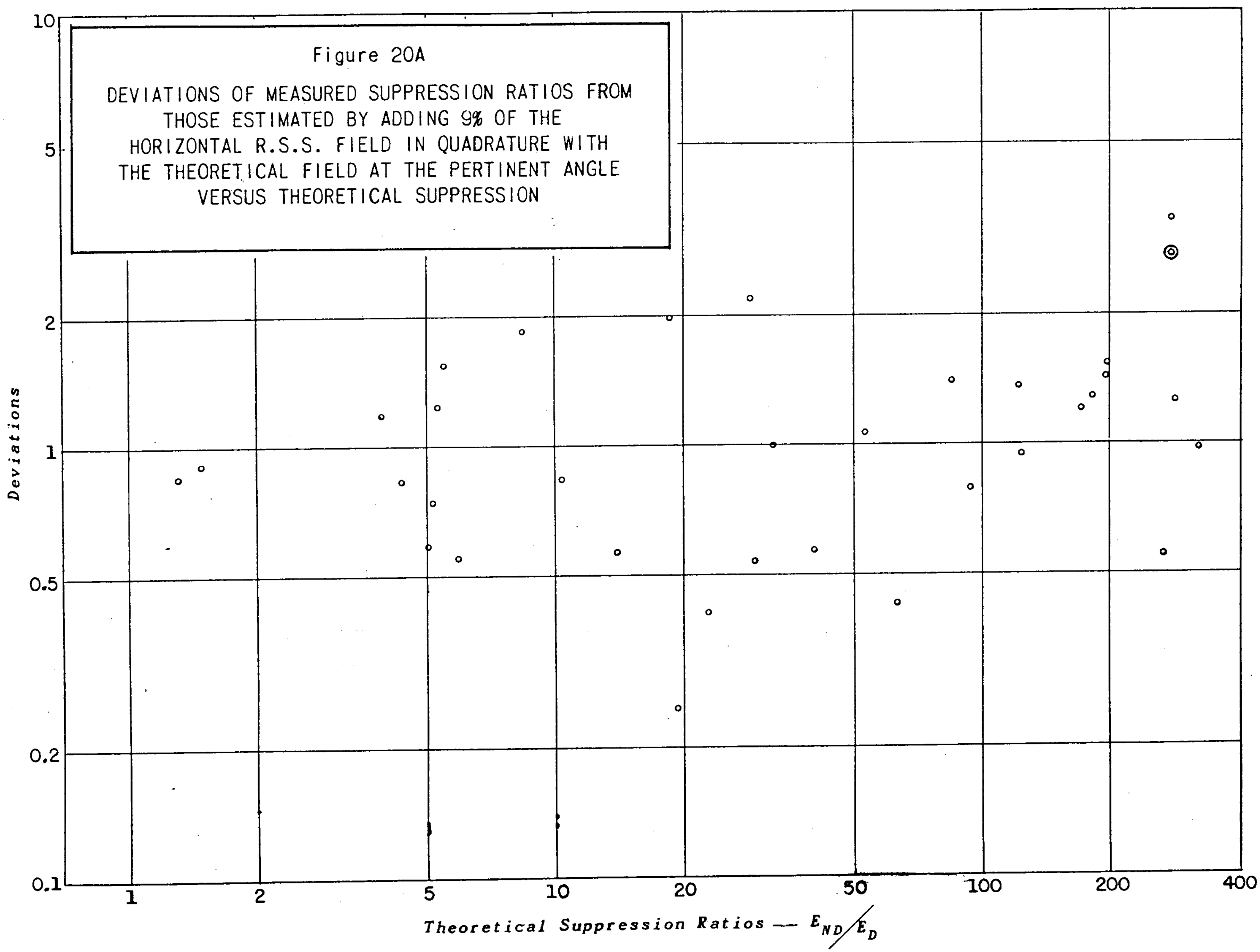


Figure 20A
DEVIATIONS OF MEASURED SUPPRESSION RATIOS FROM THOSE ESTIMATED BY ADDING 9% OF THE HORIZONTAL R.S.S. FIELD IN QUADRATURE WITH THE THEORETICAL FIELD AT THE PERTINENT ANGLE VERSUS THEORETICAL SUPPRESSION
Deviations
10
5
2
1
0.5
0.2
0.1
1
2
5
10
20
50
100
200
400
Theoretical Suppression Ratios — E_{ND}/E_D

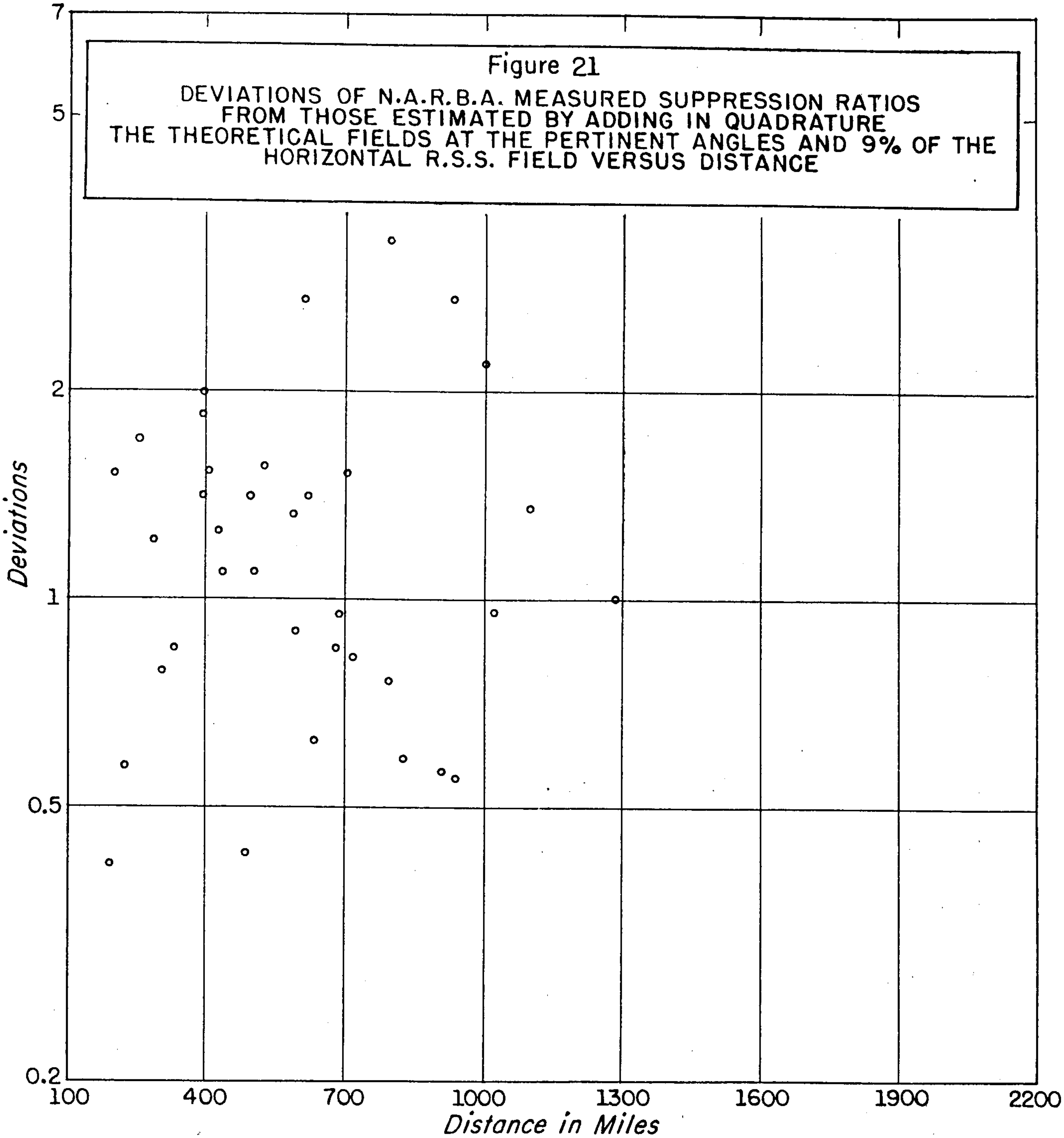
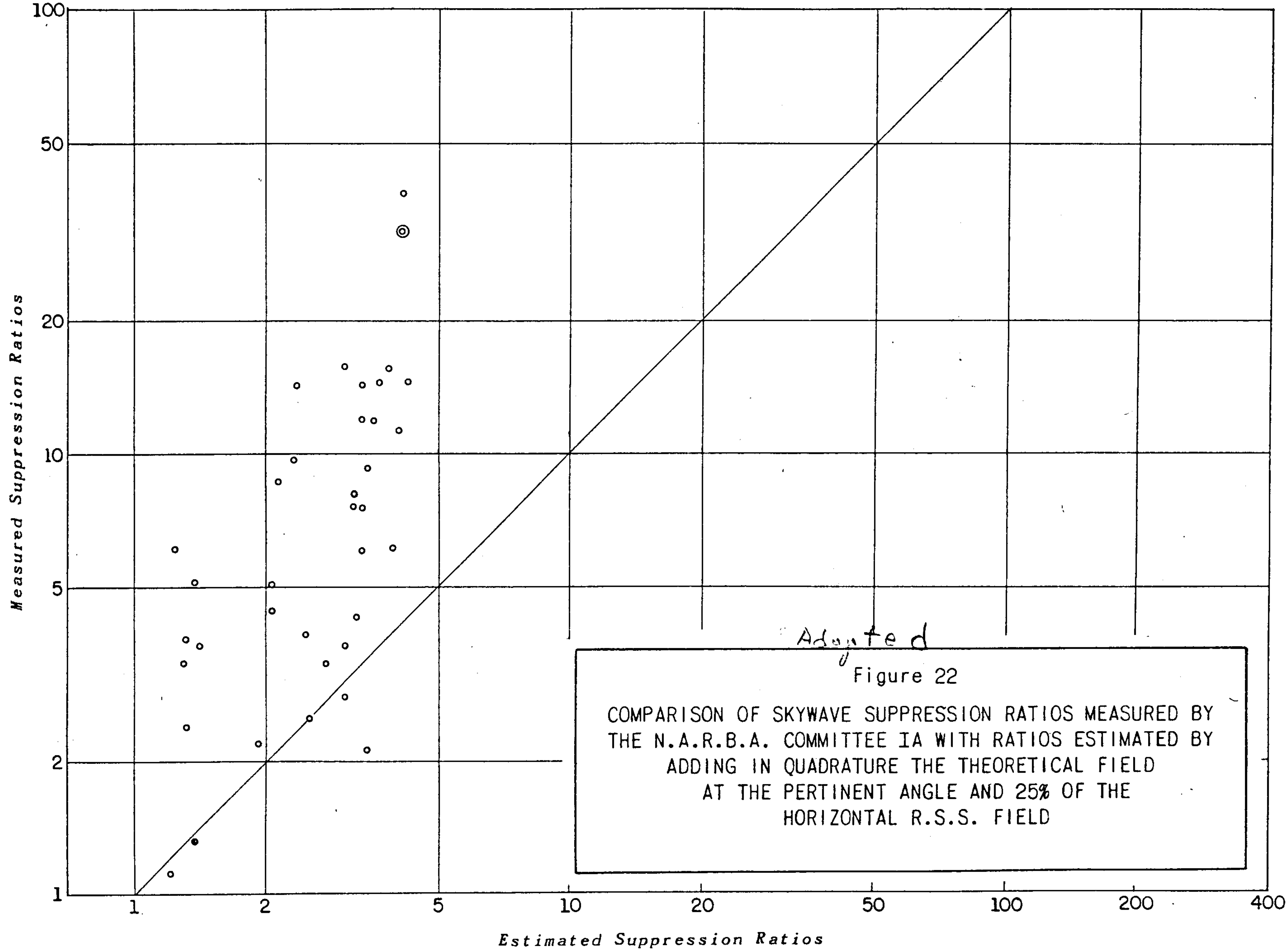


Figure 21
DEVIATIONS OF N.A.R.B.A. MEASURED SUPPRESSION RATIOS FROM THOSE ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELDS AT THE PERTINENT ANGLES AND 9% OF THE HORIZONTAL R.S.S. FIELD VERSUS DISTANCE
Deviations
7
5
2
1
0.5
0.2
100
400
700
1000
1300
1600
1900
2200
Distance in Miles



Adapted

Figure 22

COMPARISON OF SKYWAVE SUPPRESSION RATIOS MEASURED BY THE N.A.R.B.A. COMMITTEE IA WITH RATIOS ESTIMATED BY ADDING IN QUADRATURE THE THEORETICAL FIELD AT THE PERTINENT ANGLE AND 25% OF THE HORIZONTAL R.S.S. FIELD